DEPARTMENT OF SCIENTIFIC
AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

SOUTH WALES

(*SECOND EDITION*)

by

J. PRINGLE, D.Sc. (Wales)

and

T. NEVILLE GEORGE, D.Sc., PH.D.

(*Professor of Geology in the University of Glasgow*)

LONDON: HIS MAJESTY'S STATIONERY OFFICE

1948

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(*A*.6070)

A.—COAST SCENERY NEAR ST. DAVID'S.

(For description of plate, *see* p. v.) (*A*.6057)

B.—COAST SCENERY BETWEEN SOLVA AND NEWGALE.

SOUTH WALES

I. INTRODUCTION

SOUTH WALES IS not readily defined topographically. Northwards it merges into the mountains of Central Wales, which in their turn are closely linked with those of North Wales. On the east, the Breconshire plain and the Brecon Beacons are structurally and physically one with the Herefordshire plain, the hills of Radnor Forest and Clun Forest, and the Black Mountains. Only in the south-east, where the bold marginal escarpment of the South Wales Coalfield is strongly developed, does a prominent natural line form a convenient boundary.

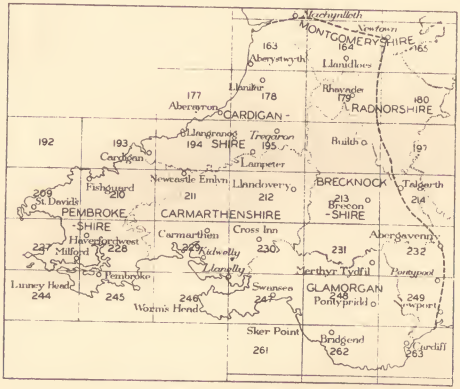

FIG. 1.—*Map of Region with Key to One-Inch Maps.*

The region now described extends southwards from the heights of Central Wales, where the valleys of the Dyfi and Severn may be considered to divide the northern from the southern mountains. An arbitrary eastern boundary, after following the scarp of the South Wales Coalfield from near Newport to Abergavenny, swings north-eastwards across a spur of the Black Mountains to the Wye Valley at Talgarth; it follows the River Wye to near Builth and then runs more or less northwards to Newtown. The area is shown on the outline map (Fig. 1), though the descriptive matter of the text, for reasons of completeness or lucidity, not infrequently refers to localities beyond the boundary.

Geological History.—South Wales as a whole is a region of older rocks, all systems from the Pre-Cambrian to the Jurassic being represented. Of the Jurassic, however, only the lowest beds of the Lias occur, and there are no overlying strata of Cretaceous or, with a minute exception, Tertiary age, the next

succeeding deposits being the superficial accumulations of the Quaternary (Fig. 2).

In the region the Pre-Cambrian rocks are almost wholly of igneous origin, whereas the strata included in the Lower Palaeozoic formations, with the exception of the products of vulcanicity, are composed of sediments laid down in the sea. Those of Cambrian age were deposited on the floor of a basin or geosyncline formed of volcanic and other igneous rocks, and during Cambrian times the sea greatly extended its boundaries by gradual depression of the region, and filled a downfold which ranged in a north-and-south direction. Towards the close of the Cambrian period the downward movement was succeeded by one of uplift, and the sea-floor emerged as dry land. Following a long interval of erosion, another submergence of the region occurred, and a basin, which was orientated in a north-east to south-west or Caledonoid direction, was formed, and extended far beyond the confines of Wales. In this sea-filled depression the Ordovician and Silurian rocks were deposited. South Wales was situated near the south-eastern margin of the basin until the close of the Silurian period, when a widespread uplift raised a mountainous tract, known to geologists as St. George's Land, over what is now Central Wales, with the result that during the succeeding Lower Old Red Sandstone times the area coincided with the northern margin of a downfold which stretched southwards into Devon and Cornwall. The Welsh part was ultimately filled with sediment of freshwater facies and the region was partly elevated at the close of the Lower Old Red Sandstone into a land-mass forming the southern part of St. George's Land and possibly extending from the heights of Central and South-west Wales across what is now St. George's Channel to the Wicklow Mountains of Ireland.

After a prolonged period of denudation during Middle Old Red Sandstone times, the cycle of submergence and sedimentation was repeated at their close, and the Upper Old Red sediments were laid down on the denuded flanks of the northern land-mass. These at first were wholly of freshwater origin, but towards the close of the Upper Old Red Sandstone, owing to depression of the basin being more rapid than infilling by sediments, the sea again spread over the western part of South Wales, marking the approach of the conditions under which were deposited the typical marine limestones of the Lower Carboniferous. After deposition of these limestones partial elevation took place, and thereafter for a long period sedimentation gradually outstripped depression. The shallowing of the basin is indicated by the Millstone Grit, and its ultimate conversion into an unstable swamp of fresh or brackish water is shown by the Coal Measures rocks and seams of coal, the latter representing the accumulated remains of trees and other plants which grew at intervals on the marshlands. In other words, the Millstone Grit and Coal Measures are the sediments of a great delta or deltas deposited along the northern margin of the basin prior to the uplift at the end of the Carboniferous period.

Before the close of the Palaeozoic era the region was yet again involved in great earth-movements and uplifted, this time to form a great range of folded mountains, stretching eastwards through England, that were part of the east-and-west Armorican range. Once more a cycle of erosion, submergence, and sedimentation was initiated, and was accompanied by the incoming of a flora and fauna characteristic of the Mesozoic era. Against the flanks of the mountains composed of Palaeozoic rocks the Triassic, Rhaetic, and Liassic sediments were laid down ; the basin included the southern part of Pembrokeshire and its

shore appears to have extended approximately along the foot of the Upper Carboniferous escarpment, from Gower by Bridgend to Cardiff and the neighbourhood of Newport. The earlier of these deposits consist largely of material derived from the subaerial waste of the Old Red Sandstone and Carboniferous

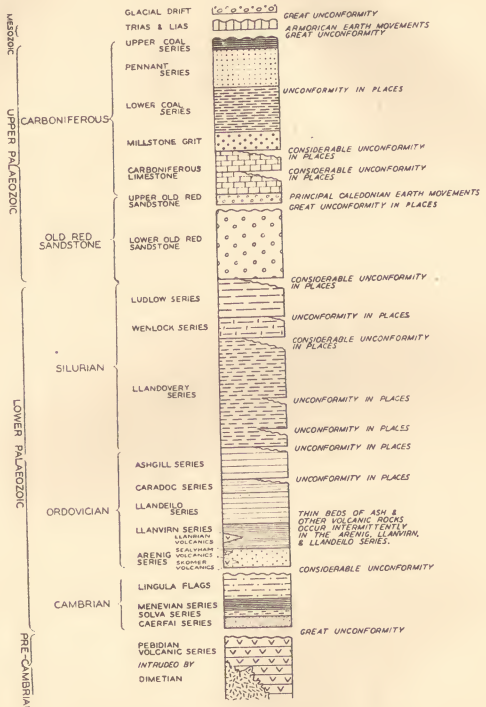

FIG. 2.—*The Rock Succession in South Wales.*
Approximate scale : 1 inch to 10,000 feet.

rocks, but as the land sank these littoral phases were succeeded by clays and limestones laid down in the deeper water of the Liassic sea.

Little is known of the geological history of the region from Lower Lias times to the Glacial period. No trace of later Mesozoic rocks has been found, but it is probable that before the close of the era much of the region had disappeared beneath the Cretaceous sea, and was covered by the Chalk. The absence of

these deposits is a measure of the enormous amount of denudation which has taken place since that time.

Structure.—As a result of repeated regional oscillation and compression, particularly during the Caledonian orogeny or period of mountain building, the original disposition of the rocks has been greatly modified. Instead of occurring as horizontal sheets, they have been bent into anticlines and synclines, and, as may be expected, the degree of folding varies considerably. The oldest formations display the greatest amount of corrugation, and bear evidence of the great lateral pressure to which the region was subjected in the cleaved character of certain of the shaly rocks, and in the numerous faults and overthrusts that fracture the strata.

Despite the complex character of the folding, however, the broad outlines of the structure of the oldest rocks are relatively simple. As O. T. Jones has shown, Central Wales is traversed by the axes of two primary anticlines, separated by a broad syncline (the Central Wales Syncline) which occupies the high ground between the rivers Towy and Teifi (Figs. 3 and 4). The axes of these folds coincide with the Caledonoid trend of the basin in which the deposits were laid down, and since the anticlines in part follow the valleys of these streams, the folds have been aptly designated the Towy and Teifi Anticlines. West of Llandeilo, however, the axial trend was modified by movements at the close of the Carboniferous period (see below), and as a result the axes curve and range east to west. Beyond Carmarthen the Towy Anticline bifurcates, one of the branches continuing westwards by St. Clears and Whitland. The extension of the Teifi Anticline in the same direction may be identified as the St. David's Anticline. O. T. Jones has drawn attention to the fact that the curve of the axes of folding coincides closely with the outline of the Cardiganshire–North Pembrokeshire coast (Fig. 3). The significance is not clear, but it is possible that the coast-line runs parallel with the axis of another primary fold.

The area occupied by the older Palaeozoic rocks is, to a great extent, determined by the inclination of the axes of the two primary anticlinal folds, and the increased width of outcrop of the Ordovician rocks towards the south-west is the result of a north-easterly pitch. Correspondingly, the synclinal tract becomes broader when followed northwards (Fig. 3).

Although there is no decisive evidence respecting the date of origin of these tectonic features, it is certain that the axis of the Towy Anticline was an important structure during the deposition of some of the Ordovician and Silurian rocks. Both folds may even be older, and it is perhaps not without significance that the Pre-Cambrian igneous masses were intruded along lines corresponding to the trend of the anticlinal axes. In Arenig and Llanvirn times, volcanic activity was conspicuous along a parallel course. Although the influence of the Towy axis was, to some extent, appreciable during the deposition of the Llandeilo rocks, it was not until Ashgill times that the structure led to the establishment of two distinctive types of deposit, one of shelly trilobitic facies laid down in shallow water to the south-east, and one of graptolitic facies deposited in deeper water to the north-west. The coincidence of the Towy axial line with the change of facies undoubtedly represents a considerable alteration of the slope of the sea-floor. The late Ordovician and Silurian deposits along the marginal tract of the geosyncline are largely of an arenaceous-calcareous character and their accumulation was frequently interrupted by uplift and erosion, while in the axial region argillaceous and non-calcareous sediments

were laid down almost continuously. Finally, as the basin filled, the influence of the folds waned, and the last sedimentary phases of the Silurian signalled the approach of the continental conditions following the elevation of St. George's Land.

Relatively minor oscillations of the sea-floor continued through Old Red Sandstone and Carboniferous times, but no major earth-movements occurred after the Caledonian until the close of the Coal Measures, when intense pressures from the south caused the buckling of the Upper Palaeozoic rocks. These were driven against St. George's Land ; and it would appear that this ridge acted in some measure as a rigid block on which the earth-waves broke. To the east, a comparable barrier of old rocks, the Malvern chain, seems to have acted in an

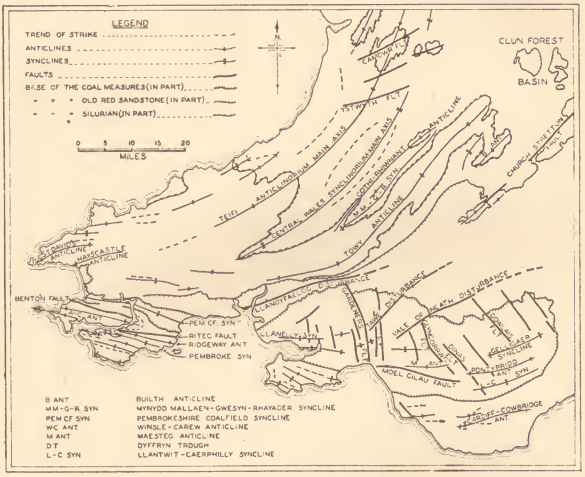

FIG. 3.—*Structural Map of South Wales.*

analogous manner, though it trends in a north-and-south direction and is pre-Caledonian in origin. In the wedge between the Towy Anticline on the north-west and the Malvern ridge, the Upper Palaeozoic rocks were relatively well protected, and as a result much of that tract is occupied by nearly horizontal beds of Old Red Sandstone that form the undulating agricultural land of Breconshire, Herefordshire, and parts of Radnorshire. Southwards, however, the post-Carboniferous folds were more intense, and in the South Wales Coalfield, the Vale of Glamorgan, Gower, and South Pembrokeshire they approximate in degree to those of the Caledonian.

The general age of these post-Carboniferous folds is that of many of the mountain blocks of North-west Europe ; in particular comparable folds are well seen in the Harz Mountains of Germany, whence the regional term of Hercynian

has been given to this orogeny. Commonly also the orogeny is called Armorican, for it is strongly developed in Brittany. Curving in a series of parallel arcs, these folds have a general east-and-west trend.

In South Wales the most obvious feature of the Hercynian orogeny is the synclinal depression of the South Wales Coalfield (Figs. 22 and 23). This extends from Monmouthshire on the east across Glamorganshire into Carmarthenshire, where it passes under Carmarthen Bay. It reappears in Pembrokeshire to form the Pembrokeshire Coalfield, and continues across the county to the sea at St Bride's Bay. Its eastern margin, between Abergavenny and Risca, has a marked westward dip, and in Monmouthshire it has the structure of a basin. The bounding upfold is the Usk Anticline, a structure that had its beginnings before the deposition of the Upper Carboniferous rocks. The Coalfield Syncline is in reality a complex downfold, consisting of a number of flexures each of which tends to diminish in magnitude when traced for any distance, and to be replaced by other flexures *en échelon*. Thus in the eastern part a central anticline, the Pontypridd Anticline, breaks the regularity of the depression, and separates two minor synclines—the Gelligaer Syncline and the Llantwit–Caerphilly Syncline. Traced westwards the Pontypridd Anticline is replaced in part by the Moel Gilau Fault, though not in a direct line. In the Neath and Tawe valleys the structure is a simple downfold, broken by faults, but to the west of Swansea the Gowerton Syncline is replaced on the north by the Llanelly Syncline. In Pembrokeshire the broad structure is relatively simple, though in detail the sediments are acutely contorted and crumpled (Pl. IIIB).

To the south of the Coalfield the Upper Palaeozoic rocks are folded into a number of anticlines and synclines arranged *en échelon*, but in none of these are Coal Measures preserved (Fig. 5). In the Vale of Glamorgan the most prominent is the Cardiff–Cowbridge Anticline, an upfold that continues the line of the Usk Anticline ; in the neighbourhood of the River Ogmore its analogue is the Candleston Anticline. A similar anticlinal axis, that of Cefn Bryn, forms the ' backbone ' of Gower, to the south of which there are subsidiary synclines, in which Millstone Grit is preserved, at Oxwich and Port Eynon. In Pembrokeshire a number of pitching folds arranged *en échelon* form the structure of the southern part of the county. In the Winsle–Carew Anticline and in the more southerly Freshwater East and Castlemartin Corse anticlines the folding is sufficiently intense to bring Lower Palaeozoic rocks to the surface ; while in the Pembroke Syncline and the Bullslaughter Bay Syncline Millstone Grit is preserved.

The Armorican folds are frequently broken by faults, some of considerable magnitude, that appear to be of approximately the same age as, or slightly younger than, the main orogeny. Some of these, such as the Moel Gilau Fault, run parallel with the strike and are obviously closely associated with the folding, and are probably fold-replacements. The Ritec and Benton Faults fall into this category, sliding along the latter having commenced at least as early as Valentian times. The majority of the faults, however, are dip faults, and have a general north-and-south trend, swinging in the east to north-west and south-east. When traced in the field they are seen to diminish in throw, and ultimately to die out ; broadly they thus appear as tear faults or sag faults. In the western part of the Coalfield they have the effect of letting down the outliers of Upper Coal Series in the Dyffryn Trough and in the Llanelly Syncline.

As already mentioned the Armoricanoid structural trend developed in the

Upper Palaeozoic rocks by pressure from the south has had an obvious effect on the earlier Caledonoid folds of South-west Wales, where the characteristic

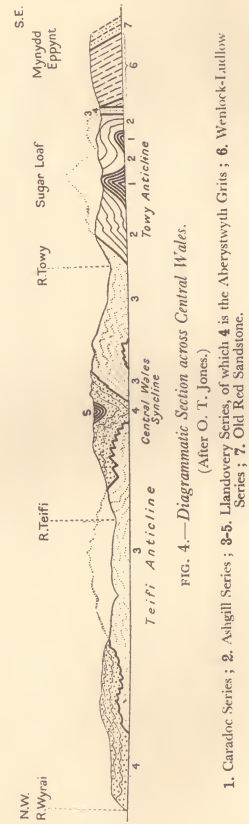

FIG. 4.—*Diagrammatic Section across Central Wales.*
(After O. T. Jones.)

1. Caradoc Series ; **2.** Ashgill Series ; **3-5.** Llandovery Series, of which **4** is the Aberystwyth Grits ; **6.** Wenlock-Ludlow Series ; **7.** Old Red Sandstone.

north-east and south-west direction of the Teifi and Towy axes is made to swing westwards into conformity with the newer superimposed folds.

The Armorican earth-movements had died down almost completely by the time of deposition of the Trias, and the Mesozoic rocks of the Vale of Glamorgan

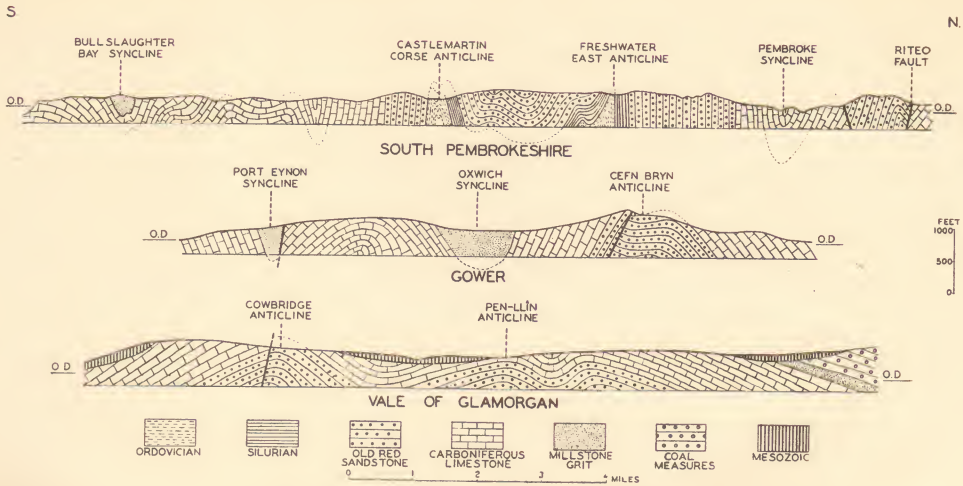

FIG. 5.—*Sections across the Armorican Folds of South Wales.*

rest with marked unconformity on the underlying Palaeozoic strata. Nevertheless, in post-Liassic times slight buckling of the Trias and Lias occurred, so that, although usually having only gentle dips, they are now rarely horizontal. By using the base of Rhaetic as a convenient datum, O. T. Jones has shown the flexures in the Mesozoic strata to have an amplitude of 400 to 500 ft., and has demonstrated that broadly the axis of the Armorican Cardiff–Cowbridge Anticline is also, in its western part, the axis of an upfold in these younger rocks ; that is, posthumous folding has occurred. He has also suggested that the syncline complementary to this upfold is perhaps represented to the south by the depression of the Bristol Channel ; this in its turn is considered to be a continuation of the Bridgewater Syncline of Somerset, a structure that probably arose during the Miocene Period, when the other major folds in the Mesozoic rocks of southern Britain—the Weald, the London Basin, the Hampshire Basin—came into being. However this may be, the folds in the Mesozoic rocks are relatively trivial, their effect on the earlier and much more acute Armorican folds being almost negligible (Fig. 5).

Two other structures deserve mention ; these are the disturbances traversing in part the floors of the Neath and Tawe valleys (Fig. 3). Neither is known certainly to reach the sea, but in the upper parts of the valleys they have a marked effect on the rock outcrops, and have obviously been a major element controlling the development of the river-system. They have a general Caledonoid trend, and in both cases they are associated with parallel anticlinal structures—the Cribarth Anticline in the Tawe Valley, and the Penderyn Anticline in the Vale of Neath—whose axes cut across the east-and-west folds of the Coalfield. In part at least they appear to be of late Carboniferous age. They may be the result of posthumous movements along deeply buried Caledonoid axes. A similar interpretation may also be applicable to the comparable Llandyfaelog disturbance that runs to the sea near Kidwelly (Fig. 3).

Since the movements that affected the Mesozoic rocks—that is, presumably since Miocene times—no appreciable flexuring of the strata in South Wales has occurred, the only later evidence for crustal warping being provided by the raised beaches and submerged forests. Slight settling along old lines of fracture, however, occasionally takes place, as is shown by the incidence of earthquakes, of which the most important occurred near Swansea in 1906.

Physical Features and Scenery.—In considerable degree, though not completely, the topography and scenery of South Wales reflect the geological structure and the geological history of the area.

The Lower Palaeozoic rocks to the north-west of the Towy Anticline, consisting largely of grits and hard shales, form high bleak moorland with only a thin capping of poor soil. Agriculture is negligible, and, except in the valleys, the population of crofters and sheep farmers is sparse. The relatively isolated Prescelly Mountains in Pembrokeshire present much the same appearance. Although there are intense folds in this tract of older rocks, they are not generally marked by obvious topographical features, and the grain of the country, owing to the uniform character of the Ordovician and Silurian sediments, is not well brought out by the distribution of hill and dale. The principal exception is the Towy Valley, which closely follows the axial line of the Towy Anticline, and of which the existence is directly attributable to that Palaeozoic structure. Farther to the north-east the valley of the Irfon between Llanwrtyd Wells and Builth follows the same upfolded belt. On the other hand the sub-

parallel Teifi Valley is not so closely adjusted to the geological structure, for its course lies a mile or two south-east of the main arch of the Teifi Anticline, and between Llandyssul and Cardigan it swings westward diagonally across the trend of the Caledonian folds. Farther north, Plynlimon itself lies on the crest of the continuation of the Teifi Anticline. The possible effect of the Caledonian folding on the development of the coast-line of Cardigan Bay has already been mentioned.

Except where they have been strongly glaciated, the Lower Palaeozoic rocks usually present a rounded regularity of outline that is broken only by the deep incision of many of the rivers. Where igneous rocks occur, however, bare crags give rise to a more varied scenery, well seen, for example, in the Builth and Llanwrtyd neighbourhoods, and in Pembrokeshire (Pl. IVA) ; in none of these districts, however, does the rugged character of the topographical line approach that of the igneous areas of North Wales. The occurrence of igneous rocks interbedded with, or intruded into, softer sediments has also a great influence on the effects of marine erosion, the differential weathering displayed, for example, along the Pembrokeshire coast from Fishguard to St. Bride's Bay contrasting greatly with the smooth sweep of Cardigan Bay. It is almost literally true that every headland between Strumble and Ramsey Island is of igneous rock and every bay and inlet carved in sedimentary strata. On the south side of St. Bride's Bay, the rocks of Skomer Island are likewise of igneous origin.

The wide expanse of gently dipping Old Red Sandstone to the north of the Coalfield is largely made of Red Marls, surmounted by the escarpment of the Senni Beds and Brownstones. Drained by the River Usk and its tributaries, much of the ground is relatively low-lying, and, the strata of Old Red Sandstone producing a richer soil than that of the Ordovician and Silurian rocks, is given over to agriculture and dairy farming to a greater degree than the Cardiganshire mountains. Even so, the heights of Mynydd Eppynt, of the Black Mountains east of Brecon, and of the Brecon Beacons are as wild and as barren as those of the Plynlimon country.

The Coalfield itself is sharply delineated by the differential erosion of hard and soft beds. The topmost grits and conglomerates of the Old Red Sandstone, tough and resistant, form the highest points of the Brecon Beacons and the Carmarthenshire Fans (Pl. IIA). Dipping gently southwards and southwestwards, with a steep northern face, they form an unbroken escarpment that runs from near Llandeilo eastwards to Brecon and Abergavenny, and then southwards through Pontypool to the Ebbw and Taff valleys. Within this major escarpment are lesser parallel ridges formed by the Carboniferous Limestone and the Millstone Grit, which dip under the low ground eroded along the outcrop of the softer shales of the Lower Coal Series. The principal east-and-west road and rail routes of the north of the Coalfield follow the outcrop, which is drained by a number of subsequent strike streams. In its turn the Lower Coal Series dips beneath the thick Pennant Sandstone, which rises as a steep and forbidding scarp to heights of nearly 2,000 ft. It forms a sinuous wall within the Coalfield (Pl. IIB), unbroken except by the incision of rivers, and includes the uplands of Blaenau Morgannwg—bare moorland, practically devoid of habitation, given over almost entirely to the rearing of a few sheep. On the other hand, the rivers of the Coalfield, deeply cleft through the escarpment, bear little relationship to the geological outcrops. A consideration of their development is given later (p. 87) ; it will suffice to mention here that they have all the appear-

(*A*.4927)

A.—THE BRECON BEACONS.

(For description of plate, *see* p. v.)

(*A*.4905)

B.—CRAIG-Y-LLYN.

(*A*.6154)

A.—CAREG CENNEN.

(For description of plate, *see* p. v.) (*A*.921)

B.—CONTORTED COAL MEASURES NEAR LITTLE HAVEN.

ance of being superimposed. Only the Neath and Tawe flow for any considerable distance along structural belts of weakness.

While differing in detail, the upland regions of the Lower Palaeozoic rocks of the Old Red Sandstone and of the Coal Measures present a general uniformity of aspect, not only because they consist largely of sandstones or toughened shales, fairly resistant to denudation, but also because they have been affected in similar ways by erosion—they have had a similar (post-Carboniferous) geological history (p. 6). Although cut by large rivers like the Towy, Wye, and Usk, these upland tracts nevertheless form a broad structural unit that is abruptly demarcated from the very different country of the Vale of Glamorgan, of Gower, and of the coastal regions of Carmarthenshire and Pembrokeshire (particularly South Pembrokeshire). Yet these low-lying areas also are composed largely of folded Palaeozoic rocks, and were at one time covered with sediments several thousand feet thick that must have towered as mountains rivalling in height those of Central Wales. The contrast in topography is thus due not to differences in rock types but to differences in erosional history : the coastal tracts have been submerged beneath the sea intermittently since early Mesozoic times, and are the eroded relics of planes of marine denudation (p. 88). Above these platforms the harder beds tend to stand out as residual monadnocks ; of these the Old Red Sandstone hills of Gower and the Tenby district are prominent, as also are the igneous intrusions near St. David's (Pl. IVB).

The coastal outline of southern and south-western Wales is more varied than that of Cardigan Bay, the Carboniferous Limestone tending to be the dom nant element of the headlands and precipitous cliffs of Gower and South Pembrokeshire (Pl. VB). Carmarthen Bay is eroded partly in the softer shales of the Millstone Grit and Coal Measures, partly in the Red Marls of the Old Red Sandstone. Swansea Bay also owes its existence to erosion along the shale outcrop of the Millstone Grit and the Lower Coal Series. In the Vale of Glamorgan the Lias limestones form bold cliffs along part of the coast between Southerndown and Lavernock.

History of Research.—It is unnecessary here to provide any detailed account of the growth of geological knowledge in South Wales, as this has recently been done in the comprehensive works by North listed in the references below, and is further reflected by the magnificent collections displayed in the geological galleries of the National Museum of Wales at Cardiff. Incidental reference to the more important workers is, however, made in the appropriate contexts.

The authors wish to acknowledge the assistance received from Dr. E. E. L. Dixon, who has supplied most of the material forming the basis of Chapter VI ; and from Miss O. F. Tassart, Dr. C. J. Stubblefield, Dr. R. Crookall and Mr. W. Dewar, who are responsible for the illustrations of fossils.

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II. THE PRE-CAMBRIAN SYSTEMS

THE OLDEST ROCKS of the region are confined to Pembrokeshire. They are the products of a period of great igneous activity which marked one of the later phases of Pre-Cambrian times and it is possible that they correspond to the Uriconian Volcanic Series. There is no trace of an underlying platform of gneiss and schist, as in Shropshire, but the occurrence of pebbles of quartz-

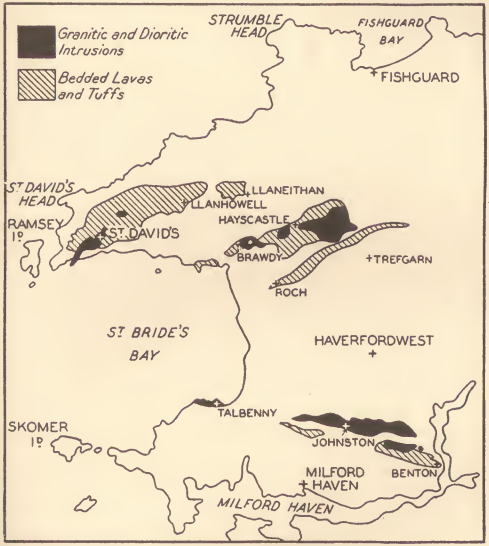

FIG. 6.—*Map showing the Distribution of Pre-Cambrian Rocks in Pembrokeshire.*

schist in the Arenig conglomerates near Carmarthen suggests that such rocks may be present under the Coalfield.

The rocks fall into two groups : a volcanic group and an intrusive group ; the course of their outcrops is shown in Fig. 6. The former, originally described by Hicks under the term Pebidian, includes variously coloured rhyolitic and trachytic tuffs with interbedded flows of lava. The tuffs were later invaded by masses of acid igneous rocks, and these plutonic intrusions, which include granite, granophyre, quartz-porphyry, and quartz-diorite, form the Dimetian of Hicks's classification. Both groups were highly folded and extensively denuded before the beginning of Cambrian times.

Pebidian.—In the neighbourhood of St. David's, the Pebidian tuffs occupy a broad anticlinal area which extends inland for several miles in an east-north-east direction. They are well displayed in the cliffs to the south and west of the city, and the sections in the area became classical on account of the controversy respecting the age of the tuffs and associated intrusions. The most recent description of the rocks is that given by Green, who has established the following subdivisions in descending order of age :—

	Thickness in feet
Ramsey Sound Series—fine-grained sericite-tuffs	700
Caerbwdy Series—greenish acid rocks with a quartz-chlorite matrix ; bands of halle-flinta and conglomerate (Clegyr Conglomerate)	2,400
Treginnis Series—hard gritty rocks with abundant trachytic pumice and boulders of red keratophyre	600
Penrhiw Series—gritty red and green tuffs passing down into red and green halleflinta, base not known	1,000

At the eastern end of the area the pyroclastic rocks form two horst-like masses, and these have been studied by T. G. Williams, who has separated them into two groups, the Treglemais Group and the Treffynnon Group. The former appears to correspond with the Caerbwdy Series and the latter to the higher Ramsey Sound Series. Representatives of the Penrhiw and Treginnis Series, however, have not been detected.

About 8 miles east of St. David's is another anticlinal area (Hayscastle Anticline) occupied by Pre-Cambrian rocks. It runs approximately parallel to the St. David's mass, from which it is separated by the complementary syncline (Tremaenhir Syncline) occupied by Lingula Flags and Arenig strata, and extends inland from near Pointz Castle to the Western Cleddau. In this outcrop H. H. Thomas and O. T. Jones have shown that the volcanic series includes several types of pyroclastic rocks ; in the lower portion, the Pont-yr-hafod Group, the tuffs are andesitic in character, and in the upper, the Rhindaston and Gignog Group, they are rhyolitic and keratophyric. The latter beds are associated with rhyolite and quartz-keratophyre lavas, some of which show marked fluxion structure.

Although direct proof of age is lacking, it is now generally agreed that the Roch Rhyolites and associated Nant-y-Coy Beds in the Roch-Trefgarn Anticline are of Pre-Cambrian age. The rhyolitic lavas and tuffs occupy an almost continuous ridge from Roch Castle to the Cleddau Valley and beyond to Ambleston ; they form the picturesque crags of Maiden's Castle and Poll Carn (Pl. IVA), and are well displayed in the Trefgarn Gorge. The rhyolites are greenish-blue, white weathering, fine-grained, silicified rocks and are associated with flinty tuffs of blue-green and pale mauve tints. They are conformably overlain by flaggy tuffs (Nant-y-Coy Beds) which are probably about 600 ft. thick. The latter are considered to be the equivalents of the Ramsey Sound Series.

Separated by several miles from the St. David's district, two distinct series of igneous rocks occur along the southern boundary of the Pembrokeshire Coalfield, where they have been brought up by the Benton fault system. The extrusive rocks have been termed the Benton Series and are probably of Pebidian age. The series which extends from Benton Castle on the River Daucleddau to Rosemarket includes flows of an acid character, such as felsites and banded and spherulitic rhyolites, interbedded with fine-grained tuffs and breccias. Some of

these beds may represent brecciated lava flows. Near Roman's Castle farm the rhyolite is a pink and greenish rock with large and conspicuous spherulites.

Dimetian.—As already mentioned, the tuffs were invaded at a later date by acid masses, comprising granite, quartz-porphyry, quartz-diorite, etc. ; the distribution of these intrusive rocks is shown on Fig. 6. Of these intrusions in the St. David's Anticline the best known is the granite or alaskite-granophyre at St. David's. It is a highly siliceous coarse-grained rock of which the principal constituents are quartz, orthoclase, oligoclase and chlorite. The granite is traversed by bands in which the rock is greatly crushed.

The quartz-porphyry is obviously related petrographically to the granite and was probably a product of the same magma. It also is a coarse-grained rock, and consists of large phenocrysts of quartz set in a fine-grained ground-mass of intergrown crystals of quartz, alkaline feldspar and a little biotite. A similar rock is found at the east end of the district around Llanhowel.

A small intrusion of diorite occurs at the north-east corner of the area at Hollybush Quarry. It is a medium to coarse-grained greenish rock, and consists of an intergrowth of white feldspar and hornblende with a small amount of quartz and biotite. The hornblende crystals frequently attain a length of three-quarters of an inch. In places the quartz is present in sufficient quantities to make the rock a quartz-diorite, and although it differs from the diorite at Knaveston, presently to be described, it shows a relationship with the quartz-diorites of the Johnston Series (see below).

In addition to the major intrusions there are also dykes of hornblende-porphyry and dolerite cutting the Pebidian, but their Pre-Cambrian age has yet to be proved.

In the Hayscastle area the Dimetian granite and quartz-porphyry are similar to those of St. David's. The diorite which occupies a small area near Knaveston, however, has no parallel. The rock consists of hornblende, albite-oligoclase feldspar, a little augite, much sphene, with ilmenite and apatite as accessory minerals.

The Johnston Series, which occurs along the southern boundary of the Pembrokeshire Coalfield, occupies an area between Llangwm and Johnston and beyond, a smaller outcrop forming the cliffs facing St. Bride's Bay, north of Talbenny ; the rocks are quartz-diorites, quartz-albite rocks, and quartz-dolerite. It is not known whether these are intrusions or whether they form the floor on which the lavas of the Benton Series rest. The quartz-diorite is an aggregate of quartz, alkali feldspar, hornblende, and biotite. It grades into a rock approaching a soda-granite in composition. Intruded into the masses of quartz-diorite are veins of quartz-albite, and cutting all the types are dykes of quartz-dolerite. The latter vary in thickness from 9 in. up to 10 ft. ; usually they have chilled margins. Occasionally some of these dykes intersect others of earlier age.

Many of the acid rocks near Talbenny have a well-marked gneissose structure. The foliation is believed to be due to post-consolidation movements. Cambrian rocks being absent, direct proof of the age of the plutonic rocks is lacking, but there seems little doubt that they belong to the Pre-Cambrian.

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III. THE CAMBRIAN SYSTEM

LIKE THEIR EQUIVALENTS in other parts of the British Isles, the Pre-Cambrian rocks were folded and elevated before the beginning of Cambrian times. There is no information directly bearing on the question of how long the Pre-Cambrian rocks existed as land, but it is evident that great erosion took place during the period of emergence ; later, when the region was converted into a basin of deposition, the earliest sediments were those due to the denuda-

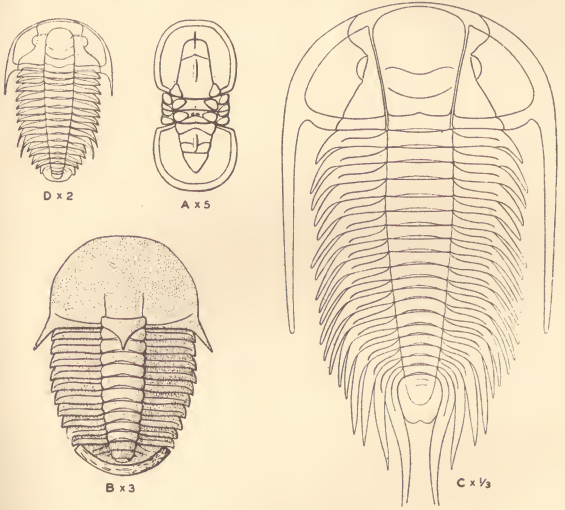

FIG. 7.—*Cambrian Fossils.*

Middle Cambrian.—**A**, *Agnostus fissus* [Lundgren MS.] Linnarsson ; **B**, *Hartshillia inflata* (Hicks) : **C**, *Paradoxides davidis* Salter. Upper Cambrian.—**D**, *Olenus cataractes* Salter.

tion of the igneous rocks, and a marked unconformity occurs between the two formations.

The sea appears to have remained comparatively shallow throughout Cambrian times. In the lower part of the formation the rocks are principally sandstones and at the base there is a thick bed of conglomerate. A slight deepening of the basin, however, is indicated by the flaggy mudstones forming the middle part, but a return to shallow-water conditions is suggested by the sandy character of the beds of the highest subdivision represented. It is not known whether still higher Cambrian beds were laid down in the basin ; if so, then

they were removed by denudation which followed re-emergence of the area as land before the deposition of the Ordovician. No volcanic rocks of Cambrian age are known to occur in the region.

Greater interest is centred in the Cambrian rocks than in those of any other formation, since they contain the earliest records of marine life. The fossils include sponges, brachiopods, lamellibranchs and trilobites. The last are the highest forms of life in Cambrian times, and they serve as zonal indices (Fig. 7). Graptolites, which are the characteristic fossils of the succeeding Ordovician and Silurian formations, appear elsewhere in the Tremadoc Beds at the top of the Cambrian, but these strata are unrepresented in the district.

Like those of the Pre-Cambrian rocks, the outcrops of the Cambrian are confined to Pembrokeshire. Excellent sections are exposed in the cliffs between Newgale and St. David's, particularly in the headland separating the bays of Caerfai and Caerbwdy (Pl. I and Fig. 8), where the beds dip steeply off the flanks of the Pre-Cambrian mass. After the publication of the first geological map of the region detailed studies of the Cambrian rocks were made by Hicks, and the divisions which he established are as follows, with some slight modifications :—

		Thickness in feet
Lower Lingula Flags	Thin siliceous sandstones and grey shales with *Lingulella davisi*, *Olenus cataractes*, and *Agnostus pisiformis* var. *obesus*	2,000
Menevian Series	Coarse grits and shales with *Billingsella* [*Orthis*] *hicksi*	100
	Dark flaggy mudstones with *Paradoxides davidis*	350
	Grey flags with *Paradoxides hicksi*	300
Solva Series	Grey flags with *Paradoxides aurora* and *Bailiaspis dalmani* [olim *Conocoryphe bufo*]	150
	Green and purple mudstones and sandstones with *Ctenocephalus* [*Conocoryphe*] *solvensis*	250
	Green pebbly sandstones with *Paradoxides harknessi*, *P.* [*Plutonia*] *sedgwicki*, etc.	150
Caerfai Series	Purple feldspathic sandstone (Caerbwdy Sandstone)	500
	Red shales with '*Olenellus*', etc.	40
	Green fine-grained feldspathic sandstones, unfossiliferous	250–300
	Reddish conglomerate	60

Caerfai Series.—The basal conglomerate has a striking appearance due to the red and pink colour of its pebble-constituents ; these are largely composed of quartz, quartzite, and acid tuffs, some of which are derived from the underlying Pebidian rocks. It reposes unconformably on various members of the Pre-Cambrian ; thus south of St. David's it cuts across the Ramsey Sound Series and comes to rest on the top of the Caerbwdy Series, as shown in sections in the Caerbwdy Valley. Most of the junctions with the Dimetian rocks are faulted, but near Porth Clais, Green has proved the conglomerate to rest without disturbance on the Dimetian granophyre.

The conglomerate is followed by fine-grained green feldspathic sandstones which so far have failed to yield fossils. The beds owe their colour to the presence of chlorite and epidote, but towards the top the green tint is replaced by a dull purple, thus indicating the approach of the conditions which prevailed during the deposition of the overlying red shales. The latter, on account of the bright red colour, are a conspicuous feature in the cliffs at Caerfai, at Castell on Ramsey Sound, and at Cwm-mawr near Newgale.

The red shales, which show current-bedding in the lower part, form the

lowest horizon from which fossils have been obtained. Hicks recorded '*Lingulella ferruginea*, *L. primaeva*, *Discina*, and *Leperditia*', and fragments of trilobites were noted by him at Castell. At Crow Cwm, near Pen-y-cwm, a fragment found by Pringle and identified as the hypostome of '*Olenellus*', may possibly belong to the ostracod *Indianites ?* [*Leperditia*] *cambrensis* (Hicks). Several layers of the red shale appear to have been bored by marine worms, and the burrows have later been filled with reddish mud. Fossils, however, are extremely rare.

The approach of the conditions under which the highest member of the Series (Caerbwdy Sandstone) was laid down is marked by the incoming of

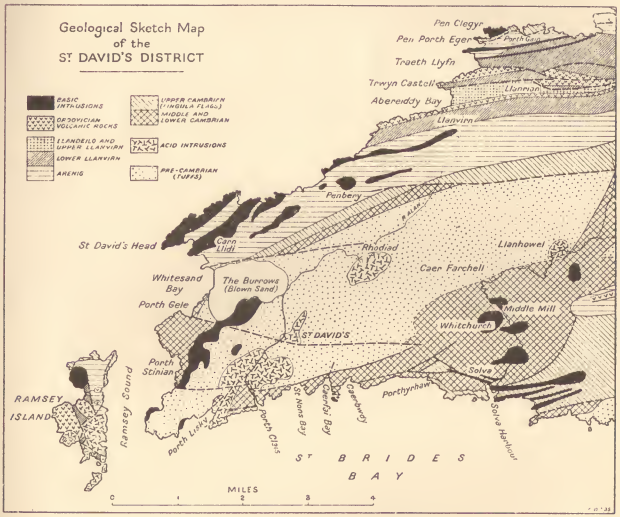

FIG. 8.—*The St. David's District.*

purplish-grey sandy layers near the top of the red shales. The sandstone itself is a fine-grained feldspathic rock, purple in colour, and contains no fossils. About 150 ft. below the top of the sandstone is a brick-red micaceous band. At a still higher level in Caerbwdy Bay the sandstone becomes coarser and carries small granitic pebbles that may have been derived from the Dimetian granophyre.

Solva Series.—The subdivisions of this Series are well shown in Solva Harbour, on the west side of Caerbwdy Bay as far as Pen Pleidiau (Fig. 8), and on the cliffs to the west of Ogof Llesugn. East of Caerbwdy they are introduced by a magnificent overfold. On the northern coast, north-west of Granston, three outcrops of rocks referred to this formation have been described by A. H. Cox.

The basal beds are coarse pebbly sandstones and rest on an eroded surface of the Caerbwdy Sandstone ; they pass up into micaceous sandstones, the whole forming the Lower Solva subdivision of Hicks. These are of great interest in that they have yielded the trilobites *Agnostus cambrensis*, *Eodiscus* [*Microdiscus*] *sculptus*, *Bailiella* [*Conocoryphe*] *lyelli*, *Paradoxides harknessi* and *Paradoxides* [*Plutonia*] *sedgwicki*, and the remains of one of the earliest sponges, *Protospongia major*. The sudden appearance of this fauna is striking, and suggests that the discordance at the base is of considerable stratigraphical importance.

On the west side of Caerbwdy Bay, the beds of the Lower Solva are followed by evenly bedded greenish sandstones, purple and green mudstones and grey flags. These constitute the Middle Solva subdivision of Hicks, and are in all about 250 ft. thick. Their original thickness, which must have been greater, is not displayed owing to strike faulting. They have yielded, amongst other species, *Ctenocephalus* [*Conocoryphe*] *solvensis*. A greater thickness is exposed in Solva Harbour, where purple bands appear near the top. The Upper Solva Beds consist of about 150 ft. of grey flags with *Paradoxides aurora* and other species of trilobites. The rocks were included in the Menevian, as originally defined by Hicks.

Menevian Series.—During the deposition of this formation, slightly deeper water appears to have prevailed over the area, and striped shales and mudstones carrying an abundant trilobite fauna were deposited. They are well displayed at Porth-y-rhaw, where they are followed by about 100 ft. of coarse grits and shales with the brachiopod *Billingsella* [*Orthis*] *hicksi*. Good sections repeated by faults may be seen in the sides of the valley leading down to Porth-y-rhaw. The *Orthis hicksi* beds mark the commencement of conditions which prevailed during the deposition of the higher Lingula Flags ; and but for a record of *Paradoxides* and *Conocoryphe* by Hicks it would have been more appropriate to regard the grits as forming the base of the Lingula Flags.

The dark shales and mudstones, characterized by an abundance of trilobites, fall into two zones, the Zone of *Paradoxides hicksi* and the Zone of *P. davidis*. In the lower the shales are striped and contain, in addition to the zonal fossil, *Agnostus fissus*, *A. exaratus*, *A. sulcatus*, *Eodiscus punctatus* var. *scanicus* and *Solenopleura applanata*. In the higher zone the giant trilobite *Paradoxides davidis* occurs in dark flaggy mudstones in association with *Holocephalina primordialis*, *Agnostus altus*, *A. exaratus*, *Eodiscus punctatus*, *Menevia* [*Erinnys*] *venulosa*, *Hartshillia inflata*, *Solenopleura variolaris*, and the shells *Acrotreta sagittalis* and *Hyolithus penultimus*. On some layers *Protospongia fenestrata* is abundant.

The Menevian Series is present in several inland sections but as a rule is poorly exposed, except in the railway-cutting at Ford near Wolf's Castle, where T. C. Nicholas has found fossils characteristic of the Zone of *P. hicksi*.

Lingula Flags.—As is indicated by the *Orthis hicksi* grits, the close of the Menevian was marked by an uprise of the sea-floor, and in shallower waters were laid down about 2,000 ft. of olive and dark-coloured micaceous and flaggy shales, and sandy mudstones interbedded with bands of siliceous sandstone, some of which show a peculiar curly bedding ; they are referred to the Lingula Flags. The basement beds are seen at Porth-y-rhaw and in the road leading down to that inlet, but although the subdivision occupies considerable areas inland, the junction with the Menevian is seldom exposed, and the boundaries of each outcrop are probably faulted. The Lingula Flags form the highest member of the Cambrian present in the region. At one time Tremadoc rocks

were believed to occur, but later studies have shown the beds to be of Arenig age (p. 24).

The flaggy shales are not highly fossiliferous, but in places, as at Whitesand Bay and on Ramsey Island, certain bedding-planes are crowded with the shells of *Lingulella davisi*. At Trefgarn Bridge in the Cleddau Valley trilobites have been obtained ; these include *Agnostus pisiformis* var. *obesus*, *Olenus cataractes*, and *O. mundus*, and indicate that the beds belong to the lower part of the Lingula Flags ; they are thus equivalent to the Maentwrog Beds of North Wales.

Intrusive Rocks.—Although there is no evidence of volcanic activity in the region during Cambrian times, numerous sill-like intrusions cut the Cambrian rocks, particularly those of the Solva and Menevian Series. The date of the intrusions is difficult to determine, but it is undoubtedly later than the Lingula Flags, and may possibly be Ordovician. Some of the intrusive rocks, which are badly decomposed, have been described as hornblende-diorite-porphyries. As a rule they are fine-grained, but coarser varieties occur in the large intrusions at Solva Harbour. The sill forming the headland of Pen Pleidiau is probably a dolerite and shows well-developed columnar jointing.

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IV. THE ORDOVICIAN SYSTEM[1]

TOWARDS THE CLOSE of the Cambrian period, the region was again folded and upheaved by earth-movements which appear to have affected a great part of Britain. During emergence the pre-existing rocks of South Wales underwent extensive denudation, and when subsidence took place the Ordovician sediments were laid down on the eroded floor of the geosynclinal basin. The junction of the two systems is to be seen at two places in Pembrokeshire, namely at Whitesand Bay near St. David's and on Ramsey Island, where the Ordovician overlaps on to the Lower Lingula Flags.

The System is divided into five Series ; these are as follows in descending succession : Ashgill, Caradoc, Llandeilo, Llanvirn, and Arenig, the two first named comprising the Bala Series of older classifications. Some or all of the divisions are represented in four fairly well-defined belts, each of which trends in an east-north-east–west-south-west or Caledonoid direction. North of the St. David's Anticline, Arenig, Llanvirn, and Llandeilo rocks extend from St. David's to Cardigan and beyond to Llangranog. Still farther in the same direction inliers of Ashgill Beds are found around Plynlimon in Central Wales ; south of the axis of the same fold another outcrop runs from St. Bride's Bay to New Quay Road, while a third in which all the divisions are well developed ranges along the Towy Anticline from Haverfordwest by way of Carmarthen and Llandeilo to Llandovery and Builth. In South Pembrokeshire Llanvirn Shales are brought to the surface by the Freshwater East and Castlemartin Corse folds.

The fauna of the Ordovician rocks is richer and more varied than that of the Cambrian. Many genera appeared for the first time, the most characteristic fossils being species of trilobites, brachiopods, and graptolites (Fig. 9). The last made their entry in the highest beds of the Cambrian and reached their maximum development in the Ordovician. Their wide distribution, coupled with a narrow vertical range in time, has proved them to be useful as zonal indices not only in the Ordovician but also in the Silurian, in which they became extinct. The Ordovician graptolite zones are as follows, but those marked with an asterisk have not been recognized in South Wales. It should be mentioned that the *Climacograptus peltifer* and *Nemagraptus gracilis* zones are grouped by some authors as Upper Llandeilian, but recent Geological Survey practice has been to place them at the base of the Caradoc Series.

Ashgill Series	Dicellograptus anceps Dicellograptus complanatus*
Caradoc Series	Pleurograptus linearis Dicranograptus clingani Climacograptus wilsoni* Climacograptus peltifer Nemagraptus gracilis
Llandeilo Series	Glyptograptus teretiusculus
Llanvirn Series	Didymograptus murchisoni Didymograptus bifidus
Arenig Series	Didymograptus hirundo Didymograptus extensus Dichograptus*

[1] List of References, see p. 42.

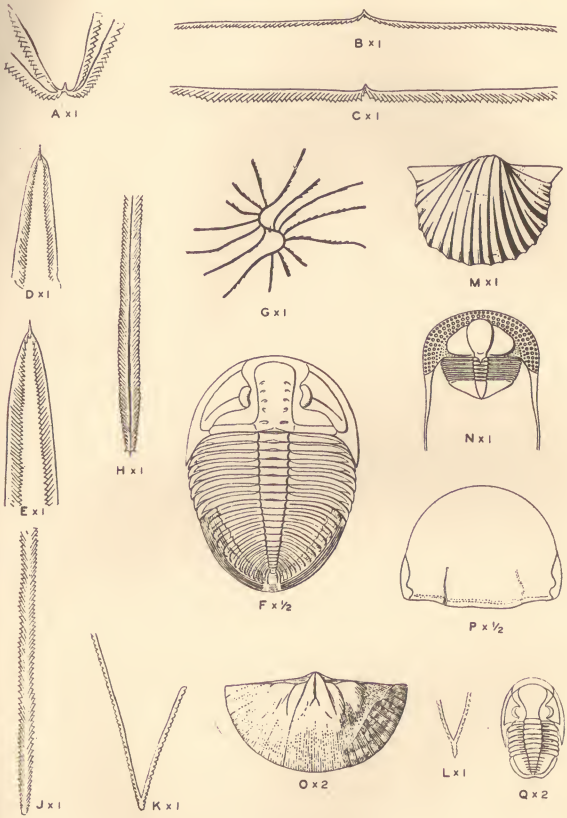

FIG. 9.—*Ordovician Fossils.*

(Graptolite drawings after Elles and Wood.)

Arenig Series.—**A,** *Tetragraptus serra* (Brongniart) ; **B,** *Didymograptus extensus* (Hall) ; **C,** *Didymograptus hirundo* Salter. Llanvirn Series.—**D,** *Didymograptus bifidus* (Hall) ; **E,** *Didymograptus murchisoni* (Beck). Llandeilo Series.—**F,** *Ogygiocaris* [*Ogygia*] *buchi* (Brongniart). Caradoc Series.—**G,** *Nemagraptus gracilis* (Hall) ; **H,** *Diplograptus* [*Mesograptus*] *multidens* Elles and Wood ; **J,** *Orthograptus truncatus* Lapworth ; **K,** *Dicranograptus brevicaulis* Elles and Wood ; **L,** *Dicranograptus clingani* Carruthers ; **M,** *Orthis* (*Nicolella*) *actoniae* J. de C. Sowerby ; **N,** *Cryptolithus* [*Trinucleus*] *concentricus* auctt. Ashgill Series.—**O,** Internal mould of ventral shell of *Sowerbyella sladensis* O. T. Jones ; **P,** cephalon of *Illaenus bowmanni* Salter ; **Q,** *Phillipsinella parabola* (Barrande).

In the shelly facies it is possible to establish a similar succession of life-zones based on the vertical range of the brachiopods and trilobites ; these, however, do not exactly correspond to the graptolite divisions.

At various stages during the accumulation of the Ordovician rocks great igneous activity prevailed throughout the region, particularly in Arenig and Llanvirn times. The majority of the volcanoes were submarine, and the lavas are usually associated with beds of tuff, ash, breccia, conglomerate and agglomerate. The extrusion of the lavas appears to have been in the order of succession from basic to acid.

Arenig Series.—The Arenig rocks comprise grits, sandstones, sandy mudstones, and dark chocolate-stained shales. This order of upward succession indicates accumulation in a relatively shallow basin which gradually deepened. In the lower part of the formation lavas and associated tuffs and ashes are present, and attain a great thickness in West Pembrokeshire.

On Ramsey Island the base consists of a layer of conglomerate, from which H. P. Lewis has collected the problematical organism *Bolopora undosa*, a characteristic fossil of the basement-bed of the Arenig of North Wales. Overlying the conglomerate are grey sandy mudstones which were regarded by Hicks as representing strata of Tremadoc age. On Ramsey Island they are highly fossiliferous, and yield the characteristic Arenig trilobites '*Ogygia*' *selwyni* and '*Calymene*' *tristani*. They are associated with the brachiopods *Orthis menapiae* and *O. proava*, and molluscan shells, including *Palaearca* and *Orthoceras ;* it is of interest to note that they are accompanied by the earliest crinoids (*Dendrocrinus cambriensis*) and starfish (*Uranaster ramseyensis*). To the equivalents of the mudstones on the mainland A. H. Cox has applied the names Abercastle Beds and Porth Gain Beds ; in the Trefgarn district they are in part represented by the Brunel Beds.

The upper shaly portion (Tetragraptus Shales) contains an abundant graptolite fauna, consisting of extensiform species of *Didymograptus*, such as *D. extensus*, *D. hirundo*, and *D. nitidus*. The beds are separable into a Zone of *Didymograptus extensus* below and a Zone of *D. hirundo* above. Of the other graptolites represented the most notable are *Tetragraptus bigsbyi*, *Diplograptus* (*Glyptograptus*) *dentatus*, *Glossograptus acanthus*, and the interesting form *Azygograptus*. The dendroid species *Callograptus salteri*, *Dendrograptus flexuosus*, and *Dictyonema irregularis* are especially abundant on a horizon a short distance above the lavas.

Between Haverfordwest and Carmarthen the Arenig Series shows little variation from the succession in North Pembrokeshire. The beds at the base, however, are coarser, and in the Carmarthen district the lowest shales and mudstones are interbedded with grits, conglomerates, and thin sandstones. The conglomerates contain pebbles of quartzite, rhyolite, jasper, quartz-schist, and other rocks evidently derived from an old land-area in the neighbourhood. The mudstones have yielded numerous trilobites, including *Cyclopyge* [*Aeglina*] *sp.*, *Parabolinella* cf. *rugosa*, *Peltura punctata* and '*Ogygia*' *selwyni*.

Volcanic Rocks.—Considerable igneous activity prevailed in the region in early Arenig times, and consequently there is a great thickness of lavas and tuffs in the lower part of the formation. Some of the flows, as in the Abercastle district, were poured out on the sea-floor and incorporated mud as the lava moved slowly over the sea-bottom. The principal foci of eruption lay towards the west, but andesitic and rhyolitic lavas and tuffs have been recorded from the area between Carmarthen and St. Clears.

In the western district flows of andesite associated with beds of tuff and bands of conglomerate are exhibited in the quarries near Trefgarn Bridge in the valley of the Western Cleddau. The conglomerates are of striking appearance, and are almost entirely made up of large pebbles of andesite. In section the lavas show abundant phenocrysts of albite and some rhombic pyroxene. According to H. H. Thomas they present structural similarities to andesites, but in composition the flows appear to have closer affinities to some trachytes and keratophyres.

In the Tetragraptus Shales, keratophyric lavas are found in North Pembrokeshire, at Abercastle and in the Sealyham district near Wolf's Castle. At Sealyham and in the Prescelly Hills they are accompanied by tuffs, but at Abercastle pyroclastic rocks are absent. The lavas at Abercastle have been examined by Elsden and Cox, the former of whom has described the rocks as lime bostonites, but they show a close resemblance to the keratophyres of Skomer Island.

The finest development of lavas, however, are those forming the Skomer Series of H. H. Thomas, so named after Skomer Island. They can be traced from St. Ishmael's near Milford Haven westwards through Skomer to Grassholm Island and the Smalls in the Atlantic, a distance of 26 miles. On Skomer the volcanic rocks are exhibited in magnificent cliff sections, and consist of a succession of flows interbedded with bands of conglomerate, green clays, marls, and quartzites ; tuffs and intrusive rocks, however, are rare. Neither top nor base of the series is seen on the island, but the rocks exposed reach a thickness of nearly 3,000 ft. On the mainland, where the Series is overlain unconformably by Upper Llandovery strata, it is much thinner and less varied, and the lavas perhaps correspond only to the two lowest members on Skomer. The lavas have slaggy and vesicular surfaces and show marked fluxion structure. Acid, intermediate, and basic varieties are represented, and eight rock-types have been recognized by Thomas, who described them fully in the Milford Memoir ; they are as follows : soda-rhyolite, felsite, albite-trachyte, keratophyre, skomerite, marloesite, mugearite, olivine-basalt, and olivine-dolerite.

Llanvirn Series.—The absence of any marked lithological difference between the shales of this formation and those of the underlying Arenig shows that the conditions of sedimentation remained unchanged in the basin. The Llanvirn rocks are mainly blue-black and black shales with interbedded bands of tuff and lavas. The beds were formerly included partly in the Arenig and partly in the Llandeilo of earlier classifications, but were separated by Hicks on faunal grounds under the name of Llanvirn, the type locality being near St. David's. In North Pembrokeshire the base is marked by a bed of 'chinastone' tuffs (Bifidus Ashes), but these are not everywhere so well developed. The Series is perhaps not more than 400 ft. thick in the Builth and Llandeilo districts, but it expands towards the west and near St. Clears it is estimated that the shales and ashes are nearly 2,000 ft. thick. In South Pembrokeshire the beds are incompletely exposed.

A characteristic feature of the Llanvirn rocks is the abundance of graptolites of the 'tuning-fork' type. Two zones are recognized, the *Didymograptus bifidus* Zone and the *D. murchisoni* Zone. The lower or Bifidus Zone is the thicker, and is further distinguished by the smaller 'tuning-fork' species, such as *D. artus*, *D. nanus*, and *D. stabilis ;* in the highest beds of the zone these are associated with *Didymograptus acutidens*, *D. murchisoni* var. *geminus*, *Climacograptus scharenbergi*, *Diplograptus* (*Glyptograptus*) *dentatus*, *Phyllograptus anna*, and an occasional

example of *Tetragraptus bigsbyi*. In addition trilobites are of common occurrence, and include *Dalmanitina* [*Phacops*] *llanvirnensis*, *Illaenus hughesi*, *Placoparia cambrensis*, and a species of *Trinucleus*. In the upper part of the zone *Cyclopyge* [*Aeglina*] *binodosa*, *Ampyx nasutus*, *Barrandia homfrayi*, and *Illaenus perovalis* make their entry, and the shales are also marked by the incoming of *Ogygiocaris* [*Ogygia*] *buchi*, a typical species of the Llandeilo Flags.

The base of the Murchisoni Zone in the type area is formed by a thick bed of tuff (Murchisoni Ash) which is in part equivalent to the rhyolitic ashes, agglomerate and interbedded rhyolitic lavas of Ramsey Island, Llanrian, and Strumble Head. The overlying shales are typically developed at Abereiddy Bay, where they are about 100 ft. thick ; they are remarkably fossiliferous, the bedding-planes being crowded with fine examples of *D. murchisoni* and its variety *D. geminus* and other forms. The zone has been recorded north of Builth, where the type of *D. murchisoni* was obtained, and at numerous localities in the Vale of Towy, but appears to be absent in the southern limb of the branch fold west of Carmarthen as a result of overstep by the Llandeilo Series. It has been recognized, however, in South Pembrokeshire.

Volcanic Rocks.—As already mentioned, the Murchisoni Ash is probably the equivalent of the rhyolites and tuffs of Llanrian and other localities ; the close proximity of the ash and the lavas at Abereiddy Bay has perhaps been brought about by one or several of the strike faults which traverse the shales. The extrusion of the lavas appears to have been preceded by the discharge of tuff, ash, breccia, and volcanic conglomerates, and the coarse character of some of these beds in the Bifidus Zone on Ramsey Island and on the mainland may indicate the actual sites of the vents. At Foel Fawr on Ramsey Island the tuff on which the lava rests is interleaved with seams of black shale yielding *D. murchisoni* var. *geminus* and other species of ' tuning-fork ' graptolites.

The rhyolites and associated tuffs are about 500 ft. thick near Llanrian, but on Ramsey Island they attain a great development, being from ,1,200 ft. to 1,400 ft. thick. Near Fishguard the Bifidus Shales are also succeeded by a volcanic group, which on Pen Caer, as Cox has shown, falls into three subdivisions, a lower and an upper rhyolitic series separated by spilitic pillow-lavas ; the spilites, however, appear to be absent in the Prescelly Hills.

Another centre of vulcanicity was situated near Builth, and the volcanic rocks which there occupy the core of the Builth Anticline include ashes and spilitic lavas. The flows are underlain by beds containing *Didymograptus bifidus* and are in turn followed by rocks yielding *Didymograptus murchisoni* and *Ogygiocaris* [*Ogygia*] *buchi*.

Llandeilo Series.—The conditions which produced the uniform lithological characters of the Arenig and Llanvirn rocks throughout the area were greatly modified by uplift at the beginning of Llandeilo times, and led to the deposition of different types of sediments. Thus near Llandeilo the Llanvirn shales are abruptly followed by a coarse grit (the Ffairfâch Grit), which in turn is succeeded by sandy calcareous flags and limestones (Llandeilo Flags and Limestones) ; these rocks constitute the Llandeilo Series in the type area, where they are said to attain a thickness of 2,500 ft. A series of similar rocks is exposed near Builth, where it is overlain by shales and calcareous mudstones with *Nemagraptus gracilis*.

When this development of the Series is traced westwards, however, striking changes in lithology take place, and indicate that deeper water lay in that

(*A*.6140)

A.—MAIDEN'S CASTLE AND TREFGARN GORGE.

(For description of plate, *see* p. v.) (*A*.6099)

B.—THE ST. DAVID'S PENINSULA.

(*A*.1082)

A.—CARBONIFEROUS LIMESTONE OF CASWELL BAY, GOWER.

(For description of plate, *see* p. vi.)

(*A*.1030)

B.—'THE GREEN BRIDGE OF WALES' AND THE SOUTH PEMBROKESHIRE PLATFORM.

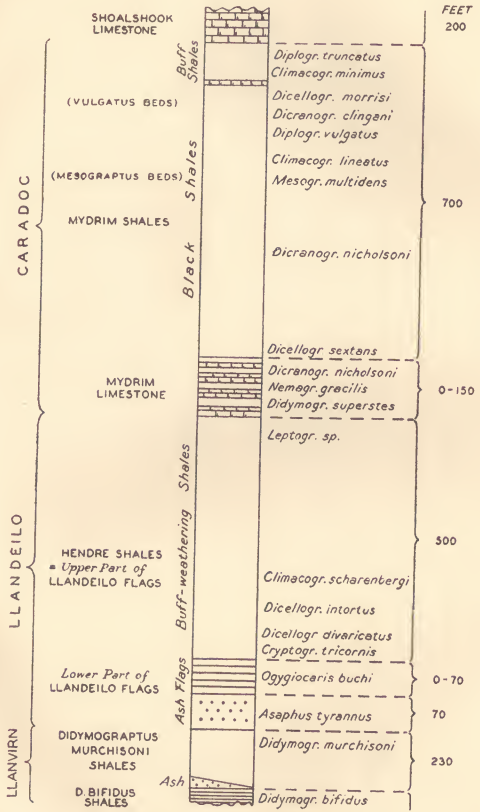

FIG. 10.—*The Llandeilo-Caradoc Succession.*
(Based upon Cantrill and Thomas.)

direction (Fig. 10). The Ffairfâch Grit passes laterally into ash and agglomerate, forming the Asaphus Ash, which averages about 70 ft. in thickness. On the north flank of the Towy Anticline the Ash can be followed westwards as far as Mydrim near St. Clears, where it disappears. In the same outcrop the Flags become thinner, and are in part represented by a thin development of flagstones above the Asaphus Ash between Carmarthen and St. Clears, but at Cuffern near Roch they rest on Murchisoni Shales. The main mass of the Llandeilo Series, however, passes laterally into brown-weathering shales (Hendre Shales), 500 ft. thick. On the southern flanks of the Towy Anticline the Ash also thins out, but the overlying calcareous flags remain more constant, and as far west as Musclewick Bay near Marloes they are at least 1,000 ft. thick. In this outcrop the flags appear to overstep on to lower horizons, and at Llan Mill near Lampeter Velfrey they rest on a high horizon in the Bifidus Shales. In the belt north of the St. David's Anticline a similar passage westwards into shales takes place. Thus near Fishguard the Llandeilo rocks are represented by flags and shales, and at Abereiddy Bay the Hendre Shales appear to rest on an eroded surface of the Murchisoni Beds. In the Prescelly Hills W. D. Evans has shown that there is an unconformity between the Series throughout the whole of the area.

The difference in lithological facies is further emphasized by the distribution of the fauna. The characteristic fossils of the flags and limestones are brachiopods and trilobites, the former including *Orthis* (*Dalmanella*) *rankini*, *Rafinesquina llandeiloensis*, and *Sowerbyella antiqua*. Amongst the trilobites the most prominent and abundant are *Ogygiocaris* [*Ogygia*] *buchi*, *Basilicus* [*Asaphus*] *tyrannus*, *B.* [*A.*] *peltastes*, *Calymene cambrensis*, and *Cryptolithus* [*Trinucleus*] *favus*. They are associated with the remains of sponges, corals, and crinoids and at some localities with graptolites.

In the Hendre Shales, on the other hand, the fauna is essentially composed of graptolites, though the trilobites *Ogygiocaris buchi* and *Trinucleus favus* are occasionally found in the lower beds. The graptolites include *Climacograptus scharenbergi*, *Cryptograptus tricornis*, *Dicellograptus divaricatus*, *D. intortus*, *D. sextans*, *Dicranograptus sp.*, *Diplograptus* (*Glyptograptus*) *teretiusculus*, *Lasiograptus* (*Hallograptus*) *bimucronatus*, and a species of *Leptograptus* ; the last occurs abundantly at Abereiddy Bay

Caradoc Series.—At the close of Llandeilo times the conditions which governed the deposition of the Hendre Shales became more widespread. This extension was mainly due to the recession of the shore-line east and south of the axial region of the Towy Anticline, and in the deeper water a fairly uniform succession of black shales (Mydrim Shales), about 500 ft. thick, succeed the Llandeilo Series. They are well exposed in the belt ranging from near Haverfordwest to beyond Builth, and in North Pembrokeshire they occur near Crymmych Arms. Around Abbey Cwm-hir, north-east of Rhayader, the Shales occupy a narrow belt on both flanks of the Towy axis and are included in the Carmel Group of Roberts. An impure limestone with black shaly partings (Mydrim Limestone), averaging about 30 ft. in thickness, is frequently present at the base of the series. At about 90 ft. from the top of the Mydrim Shales another limestone (Robeston Wathen Limestone) occurs ; this is a dark blue rock with corals, and its occurrence obviously denotes a pause in the deposition of mud over part of the area. The Mydrim Shales together with the underlying Hendre Shales constitute in the Haverfordwest district the Dicranograptus Shales of Marr and Roberts.

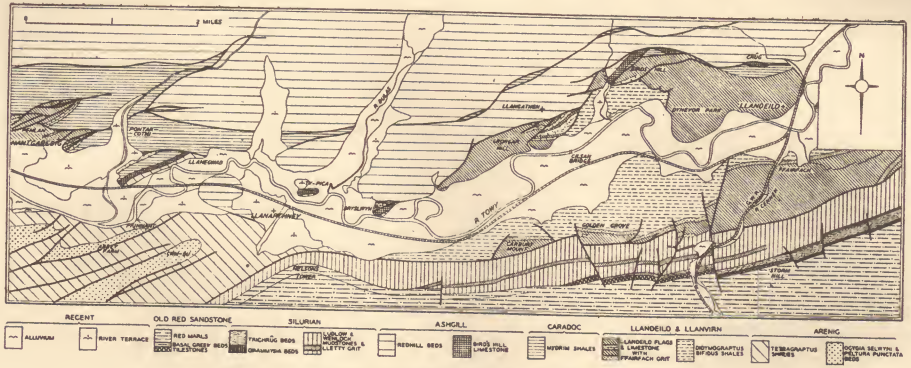

FIG. 11.—*Geological Sketch-Map of the Country West of Llandeilo.*
(H. H. Thomas and J. Pringle.)

The Mydrim Limestone at the type locality north of St. Clears is thin-bedded and shaly, and contains *Nemagraptus gracilis* and other graptolite species found in the Caradoc shales immediately overlying the Llandeilo Series at Llandeilo. It passes laterally into black shales, but reappears as limestone at intervals to the west of Mydrim. At the north end of Abereiddy Bay its equivalent is known as the Castell Limestone, and yields a typical fauna.

The Mydrim Shales are highly fossiliferous and some of the bedding-planes are covered with graptolites. With their aid H. H. Thomas divided the succession into four parts, each being characterized bycerta in species of *Diplograptus*. These are, in descending order : *Diplograptus* (*Orthograptus*) *truncatus*, *D.* (*Orthograptus*) *calcaratus* var. *vulgatus*, *D.* [*Mesograptus*] *multidens*, and *D.* (*Amplexograptus*) *arctus*. The strata broadly correspond to the lower portion of the *Pleurograptus linearis*, *Dicranograptus clingani*, and *Climacograptus wilsoni* zones of the Hartfell Shales of the Southern Uplands of Scotland. The only notable brachiopod in the Shales is a species formerly named *Orthis* (*Dalmanella*) *argentea*.

The Robeston Wathen Limestone when developed appears to occur about the position of the Vulgatus Beds. It has yielded numerous corals, including *Halysites catenularius*, *Heliolites inordinatus*, and *H. megastoma*, associated with a few brachiopods, the most characteristic of which are the orthids, *Orthis* (*Nicolella*) *actoniae* and *O.* (*Dinorthis*) *flabellulum*.

West of Haverfordwest the Truncatus Beds and the Vulgatus Beds are absent, being overstepped by the Ashgill Series. Around Keeston the lower Mesograptus Beds are also overstepped, but they are present in the faulted block of black shales at Druidston Haven which occupies the cliffs between Millstone Grit and Coal Measures.

Volcanic Rocks.—In the Llanwrtyd district volcanic rocks are found ont he stratigraphical position of the Mydrim Limestone and the lower part of the Mydrim Shales. They form an oval outcrop occupying the core of the Towy Anticline, and consist of coarse breccias and tuffs with interbedded flows of spilitic lavas showing well-developed pillow-structure, the pillows being of large size and highly vesicular. The lower breccias are separated from the lavas by shales yielding Caradoc graptolites ; between the spilites and the upper ashes are bands of hornstone, tuffs and grits and an ashy limestone with brachiopods and crinoids. The upper ashes, in which are beds of shale with *Dicellograptus sextans*, are followed by a great thichness of dark slates, much cleaved and contorted. The Llanwrtyd volcanic rocks have no analogues in South Wales, but are probably of the same age as the Upper Series of Snowdon and Cader Idris, and those in the Bala district.

Ashgill Series.—The stratigraphical breaks at the top of the Cardaoc Series indicate that movements of uplift parallel to the axis of the Towy Anticline locally affected the area. It is probable, however, that the emergence was of a relatively short duration, and on deposition being resumed sandy calcareous beds with an abundant shelly and trilobite fauna were laid down in shallow water along the southern margin of the basin. As the water deepened these deposits were followed by olive-green and grey mudstones which in places overlap on to lower horizons. The argillaceous sediments fall into two types : a southern in which the muds are calcareous and shelly, and a northern olive mudstone type that links the beds with the graptolitic shales of Central Wales.

In the country between Llandeilo and Haverfordwest the Ashgill Series is separable into three subdivisions ; in ascending order these are : Shoalshook

Limestone, Redhill Beds, and Slade Beds, the names being derived from localities near Haverfordwest. At the type locality of Shoalshook the Limestone is argillaceous, and consists of about 200 ft. of calcareous mudstones with layers of limestone nodules which weather into rottenstones. It varies in lithology, however, as may be seen in the various faulted lenticles north of the River Towy between Llandeilo and Carmarthen (Fig. 11). Thus at Crûg and Birdshill near Llandeilo, the rock is a shelly crinoidal limestone. At Crûg it is pebbly and contains small phosphatic nodules. On the southern side of the Towy axis, near St. Clears, the horizon is usually represented by a brown calcareous sandstone.

The characteristic fossils of the Limestone are cystids, brachiopods and trilobites. The cystids include species of *Echinosphaerites*, *Hemicosmites*, and *Sphaeronites*. Various brachiopods, such as *Orthis* and *Christiania*, are conspicuous, and the abundance and variety of the trilobite fauna may be judged by the occurrence of species of the following genera : *Ampyx*, *Calymene*, *Cheirurus*, *Cybele*, *Dalmanitina* [*Phacops*], *Encrinurus*, *Illaenus*, *Lichas*, *Phillipsinella*, *Proetus*, *Remopleurides*, *Sphaerexochus*, and Trinucleids. The trilobite and brachiopod faunas appear to link it with the Staurocephalus Beds of the type Ashgill region ; the presence of *Diplograptus* (*Orthograptus*) *truncatus* at Shoalshook, however, does not necessarily imply that the lower beds of the Shoalshook Limestone are of Caradoc age, as some writers have suggested.

The Redhill and Slade Beds are easily recognizable near St. Clears, Narberth, Robeston Wathen, and Haverfordwest, and form the southern type. The Redhill Beds are olive and grey mudstones with some thin-bedded sandstones. They attain a thickness of 1,200 ft. and pass up into the red-stained mudstones which constitute the Slade Beds. These are much thinner and seldom exceed 300 ft. in thickness. They are highly fossiliferous, and contain corals, crinoids, bryozoa, brachiopods, lamellibranchs, gastropods, and trilobites. Of the last many of the genera recorded from the Shoalshook Limestone occur, but the species *Chasmops conophthalmus* appears to be characteristic.

Along the northern flank of the Towy Anticline the Redhill and Slade subdivisions are not separable, the beds mainly consisting of dark olive mudstones, shelly in places, as at Camlo Hill. This northern type, as has already been mentioned, possesses lithological characters linking the shelly mudstones of the south and the graptolitic shales of Central Wales. The mudstones occupy considerable areas from Llandeilo westwards (Fig. 11) towards St. Bride's Bay, where they pass beneath Carboniferous rocks. At Llandeilo the Redhill–Slade Beds succeed the Shoalshook Limestone, but west of Carmarthen and in North Pembrokeshire they rest unconformably on Mydrim Shales. At Cotland Mill, near Llawhaden, where the northern and southern types have been brought into close proximity by faulting, there is a conglomerate in the northern mudstones containing fossiliferous pebbles with Caradoc graptolites.

Towards the axial region of the geosyncline the Ashgill Series comprises conglomerates, grits, flagstones, and shales. It is evident from the greatly increased thickness of the group that the central part of the basin was undergoing rapid subsidence, and that sedimentation, though keeping pace with the downward movement, was interrupted from time to time by uplift and erosion of the floor. The Series disappears beneath the Silurian rocks of Central Wales, but is brought up in the anticlinal inliers around Plynlimon and eastwards towards Llanidloes. In the Pont Erwyd district O. T. Jones has recognized three groups,

as follows, in ascending order: Nant-y-Môch Group, Drosgôl Group, and Bryn-glas Group. The combined thickness of the beds is about 3,400 ft., but the base is nowhere exposed. The shales interleaved with the flags of the oldest group, which itself is over 1,000 ft. thick, have yielded the zonal graptolite *Dicellograptus anceps*, along with other species. No fossils, however, have been recorded from the two higher groups. Certain gritty beds in the Drosgôl Group are of unusual interest. They exhibit a curiously gnarled and knotted appearance on weathered surfaces, and when broken the internal layers appear twisted and contorted. These features are of widespread occurrence, and have been noted in corresponding beds from places as widely apart as Llangranog, Llansawel, and Machynlleth.

Intrusive Rocks of Ordovician Age.—It has already been mentioned (p. 21) that some of the diabase-porphyrites which are intruded into the Solva Series and Lingula Flags may be of Ordovician age, but since none of them has been found to cut the Ordovician sediments, actual proof is not forthcoming. In the Ordovician rocks, particularly those in the belt north of the St. David's Anticline, numerous sill-like intrusions tend to occur along a particular horizon in the Arenig (Fig. 8). These are mainly doleritic rocks, and their vertical position is the result of the sills having been folded at the same time as the sediments; their injection therefore occurred before the folding movements.

The intrusions in the Arenig rocks range in texture from fine-grained to coarsely crystalline, and show considerable variation in silica-content. They are nevertheless intimately related and appear to have been derived from a common magma underlying the region. The type near St. David's is a quartz-enstatite-dolerite, but the closely allied rocks of Strumble Head are quartz-free. The large sills forming Carn Llidi and St. David's Head are coarsely crystalline quartz-enstatite-gabbros and often show ophitic structure, but where quartz is a relatively abundant constituent granophyric intergrowths occur. The doleritic masses of Carn Ysgubor, Pen Bery, and Porth Gain are medium to fine grained, and are distinctly more acid than the typical dolerites of the district (Pl. IVB). In the Prescelly Hills the dolerites are characterized by the presence of pink and white spots, and form a striking rock type.

In the succeeding Llanvirn Series the intrusions are acid rocks like the lavas of the period. On Ramsey Island and adjacent islets the sills are quartz-albite-porphyries. They appear to have no counterpart on the mainland and occur on a constant horizon in the Bifidus Shales, with which they have also been folded. The rocks are fine-grained with phenocrysts of quartz and albite set in a felsitic ground-mass. The quartz-porphyry sill east of St. Clears is different. This rock contains large crystals of oligoclase and orthoclase with small hornblende. North-west of Builth numerous masses of dolerite invade the Llandeilo Shales, and form a prominent ridge near Welfield. More than 40 distinct intrusions have been mapped, and Jones and Pugh have reached the conclusion that the ridge is occupied by a core of dolerite having the habit of an elongated laccolith.

A point of great archaeological interest is connected with the lavas and associated intrusions of Pembrokeshire. H. H. Thomas has conclusively proved that those in the Prescelly Hills were used in the construction of parts of Stonehenge.

Minerals.—Veins of galena have been worked near Carmarthen. These occur in Arenig rocks and range across the fold axes. The ore is associated with a little copper pyrites and zinc blende in a gangue of barytes and vein-quartz (see also p. 42).

V. THE SILURIAN SYSTEM

THE CONDITIONS WHICH controlled sedimentation at the close of the Ordovician Period continued during early Silurian times without marked change. Towards the end of the Silurian such evidence as now exists suggests that a general shallowing of the basin took place ; the sediments are more arenaceous and littoral phases mark the proximity of shore-lines. In South-west Pembrokeshire the sandstones are ripple-marked and current-bedded and the gradual disappearance of the Silurian fauna signals the approach of the 'continental' facies characteristic of the Old Red Sandstone.

The System is divided into three Series ; in descending order these are : Ludlow,[1] Wenlock, and Llandovery or Valentian. The graptolitic facies of the Llandovery includes the Tarannon or Gala rocks of authors, while the Wenlock and part of the Ludlow constitute Lapworth's Salopian.

The Silurian rocks are widely distributed in the region. Llandovery strata of graptolitic facies cover much of Central Wales, ranging from Tarannon south-westwards to the neighbourhood of Carmarthen, and from Aberystwyth along the coast to Llangranog. The shelly Llandovery, Wenlock, and Ludlow strata crop out along a narrow belt extending from Builth to a few miles beyond Llandeilo, where they are overstepped by the Old Red Sandstone. Farther west Silurian rocks occupy a tract of country between Narberth and Haverfordwest, and are also present in several inliers in South-west Pembrokeshire. It is probable that they underlie the greater part of the Coalfield, since in Glamorganshire Wenlock and Ludlow rocks are brought to the surface in the core of the anticlinal fold at Rumney near Cardiff.

With the exception of the lavas at Marloes Bay and Wooltack Park in Pembrokeshire no contemporaneous volcanic rocks are known in the region.

Although there appears to be no abrupt change in lithology at the junction of the Ordovician and Silurian, there are important faunal changes, and these serve to define the boundaries of the Systems (Fig. 12). With the exception of a few diplograptids, the varied graptolite genera which characterize the Ordovician rocks became extinct, and the older fauna was replaced in Silurian times by species of a single family, the Monograptidae. In their evolution, however, the monograptids gave rise to species characterized by distinctive morphological features ; these are of considerable chronological significance, and form the basis of a zonal scheme of classification of the Llandovery, Wenlock, and lower part of the Ludlow ; in Aymestry times graptolites became extinct in Britain. The zones are as follows :—

Ludlow Series (lower part)	Monograptus leintwardinensis	
	"	tumescens
	"	scanicus
	"	nilssoni
	"	vulgaris

[1] The Ludlow Series is followed by the Downton Series, which by some authorities, including the Geological Survey, has been classified with the Silurian. To Dr. E. E. L. Dixon and the writers, however, the evidence appears to support the inclusion of the Downton rocks in the Old Red Sandstone, and the Series is here described as belonging to that formation (see p. 47).

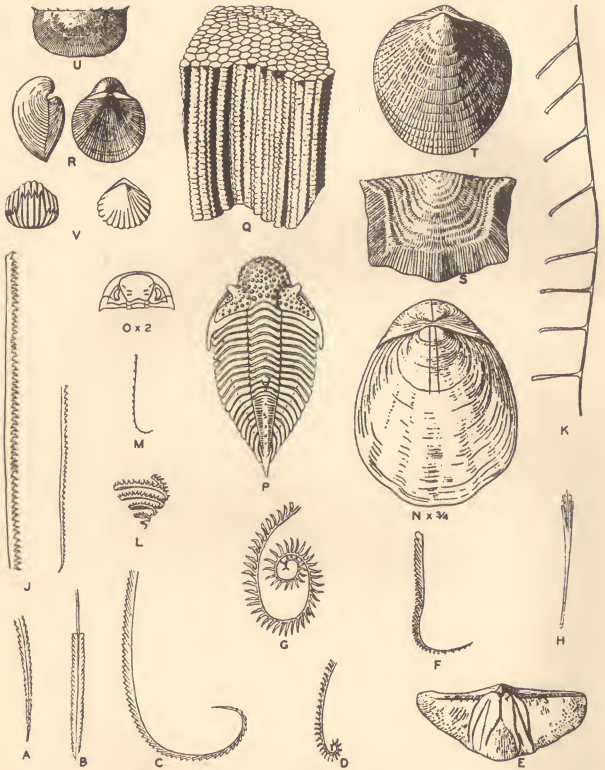

FIG. 12.—*Silurian Fossils.*

(All natural size except N and O ; Graptolite drawings after Elles and Wood.)

Llandovery Beds.—**A,** *Akidograptus* [*Cephalograptus*] *acuminatus* (Nicholson) ; **B,** *Diplograptus* [*Mesograptus*] *modestus* Lapworth ; **C,** *Monograptus cyphus* Lapworth ; **D,** *M. triangulatus* (Harkness) ; **E,** *Plectodonta duplicata* (J. de C. Sowerby), internal mould of ventral shell ; **F,** *Monograptus argenteus* (Nicholson) ; **G,** *M. convolutus* (Hisinger) ; **H,** *Cephalograptus cometa* (Geinitz) ; **J,** *Monograptus sedgwicki* (Portlock), distal and proximal parts ; **K,** *Rastrites maximus* Carruthers ; **L,** *Monograptus turriculatus* Barrande ; **M,** *M. crispus* Lapworth ; **N,** *Pentamerus oblongus* J. de C. Sowerby ; **O,** *Phacops elegans* (Sars and Boeck) ; **P,** *Encrinurus punctatus* Brünnich. Wenlock Beds.—**Q,** *Favosites gothlandicus* Lamarck ; **R,** *Parmorthis elegantula* (Dalman) ; **S,** *Leptaena rhomboidalis* (Wilckens) ; **T,** *Atrypa reticularis* (Linnaeus). Ludlow Beds.—**U,** *Chonetes striatellus* (Dalman) ; **V,** *Camarotoechia nucula* (J. de C. Sowerby).

Wenlock Series	Cyrtograptus lundgreni
	,, rigidus
	,, linnarssoni
	,, symmetricus
	Monograptus riccartonensis
	Cyrtograptus murchisoni
Llandovery Series	Monograptus crenulatus
	,, griestoniensis
	,, crispus
	,, turriculatus
	,, halli
	,, sedgwicki
	,, regularis
	,, leptotheca
	Diplograptus [Mesograptus] magnus
	Monograptus triangulatus
	,, cyphus
	,, acinaces
	,, atavus
	Akidograptus acuminatus
	Diplograptus (Glyptograptus) persculptus

Similarly, the oncoming of the Silurian was heralded in the shelly facies by the extinction of many Ordovician brachiopods and trilobites, and their disappearance was followed by the entry of new genera. Of the brachiopods *Atrypa*, *Barrandella*, *Meristina*, *Stricklandia*, and *Pentamerus* are conspicuous members of the new faunas. The most important event in the history of the fauna, however, took place at the close of the Silurian when the earliest vertebrates (fishes) made their first appearance in British seas.

Llandovery Series.—In the type area of Llandovery the formation is represented by shelly rocks deposited in the shallow waters along the marginal tracts of the basin, and separated by the Towy Anticline from those of graptolitic facies, laid down in the axial region of the geosyncline. The correlation of the two facies, however, is helped by the occasional occurrence of graptolites in the shelly beds. The succession has been divided into three parts, Lower, Middle, and Upper, each of which in the shelly facies is marked off by a plane of unconformity at Llandovery and Garth.

(*a*) SHELLY FACIES

Lower Llandovery.—The shelly Lower Llandovery rocks occupy two districts—around Llandovery, and in the country between Narberth and Haverfordwest ; they are closely similar in both outcrops. At Llandovery the basement beds are dark shales with thin bands of sandstone and conglomerate—in all about 100 ft. thick—and these are followed by about 1,200 ft. of greenish mudstones containing the brachiopods *Meristina crassa* and *M. subundata*, in association with *Climacograptus törnquisti*. These beds in turn are succeeded by a similar thickness of shelly mudstones and thin bands of sandstone with *Plectatrypa* [*Atrypa*] *marginalis*, *Barrandella undata*, *Leptelloidea scissa*, *Plectodonta* [*Sowerbyella*] *duplicata*, and *Stricklandia lens*. The occurrence of the graptolites *Monograptus incommodus* and *Climacograptus hughesi* near the top suggests that the beds may be equivalent to the upper part of the Zone of *Monograptus acinaces*.

In the Haverfordwest district the equivalent rocks are comprised in the Haverford Stage and attain a thickness of over 2,000 ft. Dark shales and sandstones, with bands of conglomerate at the base, are followed by greenish mudstones (Cartlett Beds) with *Barrandella undata*, *Diplograptus* [*Mesograptus*]

modestus, and *Climacograptus normalis*, and are probably in the Persculptus Zone. They are succeeded by sandy mudstones (Gasworks Mudstones) yielding a fauna nearly identical with that referred to the higher part of the Zone of *Monograptus acinaces* at Llandovery. The mudstones at Haverfordwest, however, are overlain by fine-grained sandstones and shale (Gasworks Sandstone) with *Sowerbyella superstes* ; these and some barren mudstones are absent in the type district.

Middle Llandovery.—The shallowing of the basin indicated by the Gasworks Sandstone was followed by uplift and erosion ; hence there is no trace of Middle Llandovery at Haverfordwest. At Llandovery and Garth signs of this uplift are apparent, but emergence was less prolonged, and was followed by the deposition of mudstone, constituting the typical shelly facies of the Middle Llandovery. The subdivision consists of about 800 ft. of mudstones with small calcareous nodules and, as already indicated, rests uncomformably on a horizon equivalent to the Gasworks Mudstones of Haverfordwest. The beds carry a distinctive fauna of brachiopods including *Stricklandia lens*, *Hebertella lata*, *Plectodonta* [*Sowerbyella*] *millinensis*, *Triplecia insularis*, and other species which have ranged upwards along with the trilobites *Calymene*, *Lichas*, and *Phacops*. A few graptolites are present, and include such species as *Climacograptus scalaris*, *Diplograptus* (*Orthograptus*) *cyperoides*, *Monograptus decipiens*, *M.* cf. *regularis*, and *M.* cf. *lobiferus*. These, in O. T. Jones's opinion, indicate the equivalence of the beds with the Zones of *Monograptus convolutus* and *Cephalograptus cometa*.

Upper Llandovery.—The shelly Upper Llandovery rocks in the type area and at Haverfordwest also show many points of similarity. Near Llandovery and Garth mudstones crowded with *Atrypa reticularis*, *Barrandella globosa*, and *Pentamerus oblongus* rest unconformably on the Middle Llandovery. These beds are followed by sandstones laid down in shallower water, and contain an assemblage of brachiopods of which *Pentamerus oblongus* is the dominant species. The sandstones are interleaved with bands of shale and are overlain by grey mudstones ; eastwards from Llandovery the mudstones appear to pass laterally into flaggy sandstones and shales with purple bands, and at Pye Corner near Gelli Hill in Radnorshire thin limestones are present, and yield *Stricklandia lirata*, *S. lens*, and *Strophonella euglypha*. In the southern part of the outcrop, near Llangadock, the Upper Llandovery rests unconformably on Llandeilo rocks (Fig. 13).

At Haverfordwest there is a thick mudstone series at the base. This forms the Millin Stage and includes the Uzmaston and Canaston Beds. These are about 1,600 ft. thick, and yield a shelly fauna similar to that of the equivalent rocks of the Llandovery area. In the narrow belt to the south of the coalfield, near Rosemarket, the greater part of the Millin Stage appears to be represented by arenaceous rocks (Rosemarket Beds) which have been laid down nearer the shore-line. The lowest beds rest unconformably on Pre-Cambrian rocks and are conglomeratic, but pass upwards into mudstones with *Pentamerus oblongus* and other characteristic brachiopods. The exact relation of the Rosemarket Beds to the Upper Llandovery of Marloes Bay and Wooltack is not known, but they are probably as low in the succession as the earliest Upper Llandovery in South-west Pembrokeshire.

In the latter area a littoral facies is developed. The succession includes conglomerates, sandstones, and quartzites, followed by about 180 ft. of grey, green, and red mudstones with *Barrandella globosa*, *Stricklandia lirata*, and *Leptostrophia compressa*. Close to the local base, flows of a basic lava are associated

with tuffs. At Wooltack Park the sequence is similar, but when traced inland the beds are seen to rest unconformably on the Skomer Volcanic Series. Rocks of Upper Llandovery age are also present in the Rumney inlier at Cardiff; at Pen-y-lan they contain the characteristic brachiopod *Pentamerus oblongus*.

(*b*) GRAPTOLITIC FACIES

As already mentioned, the Llandovery rocks occupy an extensive area in Central Wales and belong to the graptolitic facies. Along the north-western flank of the Towy Anticline from Rhayader to Conwil near Carmarthen, the Series includes shales and mudstones with grits and conglomerates prominently developed on certain horizons. Sections along the strike present a fairly uniform succession upwards, but local differences occur as a result of contemporaneous movements of uplift and erosion of the area running parallel to the main anticlinal axis.

The Lower and Middle subdivisions form an apparently unbroken succession, though locally a slight discontinuity has been detected by K. A. Davies at the base of the *D. magnus* Zone; in the Rhayader district they constitute the Gwastaden Group, 1,800 ft. thick. The succession, described by H. Lapworth, indicates a gradual deepening of the sea towards the north-west. The local base is formed by a mass of grits (Cerig Gwynion Grits). Towards the top the beds become flaggy (Dyffryn Flags) and contain *Diplograptus* [*Mesograptus*] *modestus*. These are followed by shales with *Monograptus tenuis*, *M. cyphus*, and *M. fimbriatus* (Ddôl Shales), which in turn are overlain by mudstones (Gigrin Mudstones); but since the latter yield *M. convolutus*, at least 300 ft. of the beds should be referred to the Middle Llandovery.

Farther south K. A. Davies has shown that grits comparable with those of Cerig Gwynion do not form the true base of the series, but are underlain by 35 ft. of mottled mudstones with *Diplograptus* (*Glyptograptus*) *persculptus*; the horizon has been traced from Abergwesyn to Pumpsaint.

The rocks plunge beneath Upper Llandovery strata towards the axial part of the basin, and where they are brought up in the anticlinal tracts of Pont Erwyd and Machynlleth, it is seen that the Lower and Middle Llandovery beds are greatly reduced in thickness and are of finer grain, being represented by shales and flags with a few gritty bands. They present the appearance of having been laid down in uninterrupted sequence, but it is likely that the stratigraphical breaks so prominent in the shelly facies are reflected in the sharp boundaries between the various graptolite zones. Near Ystrad Meurig, however, the occurrence of coarse grits on a horizon equivalent to the base of the Castell Group (see below) may be connected with the uplift at the close of the Lower Llandovery.

In the Pont Erwyd country the Lower and Middle Llandovery rocks constitute the Pont Erwyd Stage, which comprises three groups of strata. The lowest, or Eisteddfa Group, is 300 ft. thick; the beds are flaggy and contain a graptolite fauna mainly composed of diplograptids, such as *Diplograptus* [*Mesograptus*] *modestus*, *Climacograptus scalaris*, and *Diplograptus* (*Glyptograptus*) *persculptus*, but in the shales of the overlying Rheidol Group, 400 ft. thick, *Monograptus* and *Rastrites* enter and are associated with *Dimorphograptus* and *Climacograptus*. The Rheidol Flags are conformably followed by 250 ft. of greenish shaly rocks of the

Castell Group, the lower part of which is of Middle Llandovery age, and yields *Rastrites hybridus*, *Monograptus leptotheca*, *M. convolutus*, and *Cephalograptus cometa*. The bed with *M. leptotheca* is noteworthy ; it is a dark shale with a one-inch green-coloured band which has a wide distribution not only in Central Wales but occurs as far north as the Lake District. Near Machynlleth the Pont Erwyd Stage is represented by the Cwmere and Derwen Groups, and to the east around Tarannon by the Fachdre, Dolgadfan, and the lower portion of the Twymyn Beds. In the Llanidloes area, W. D. V. Jones has shown that the rocks included in the Clywedog Stage yield a graptolite fauna similar to that of Pont Erwyd.

After the deposition of the Middle Llandovery rocks a local elevation of the sea-floor took place west of Rhayader, and in a great hollow which was then eroded the massive Upper Llandovery conglomerates of the Caban Group were laid down. They are confined to the Rhayader district and appear to form a lenticular mass, since the beds disappear rapidly when followed along the strike ; they are also absent in the Plynlimon area, only 15 miles away. The Caban conglomerates pass up into fine grits with *Monograptus sedgwicki*, and these in turn are followed by the Gafallt Shales, the three members forming the Caban Group, 1,100 ft. thick. The grits and shales are probably the equivalents of the upper part of the Twymyn Beds of Tarannon and the lower part of the Oldchapel Mudstones of the Llanidloes Stage. South-westwards along the strike the Sedgwicki Beds pass laterally into shales and mudstones ; although of no great thickness they become thinner towards the north-west, and at Pont Erwyd the zone is represented by 108 ft. of the highest beds of the Castell Group, and by 88 ft. of shales and mudstones near Machynlleth.

The succeeding Zones of Turriculatus, Crispus, Griestoniensis, and Crenulatus are comprised in the Tarannon Series as defined by Miss E. M. R. Wood, and each presents a uniform facies throughout the area. At Tarannon the Turriculatus and Crispus Zones are represented by the bluish-black shales of the Brynmair and Gelli Beds, in all about 2,000 ft. thick, and round Llanidloes by the greater part of the Oldchapel Mudstones and the Caerau Group. In the Rhayader district their equivalents are included in the Rhayader Pale Slates, and again between Abergwesyn and Pumpsaint an argillaceous facies predominates, though bands of grit and conglomerate occur in the Turriculatus Beds. In the Griestoniensis Zone the basin appears to have become shallower, and the rocks are more arenaceous over a widespread area. Thus in the north-east they consist of about 1,150 ft. of thin-bedded greywackes and bands of grit (Talerddig and Moelfre Grits), and in the Abergwesyn country the corresponding beds are massive grits and conglomerates (Pysgotwr Grits) with bands of shale ; in both areas these are followed by green mudstones and shales with purple bands (Dolgau Mudstones), containing *M. crenulatus*.

In the Pont Erwyd and Machynlleth districts the equivalents of the Turriculatus–Crenulatus Zones are included in the Ystwyth Stage. The lowest or Devil's Bridge Group comprises about 1,500 ft. of shale and mudstone with gritty bands, while the overlying beds are included in the Myherin Group. The latter is followed first by shales, then by a gritty development, which, as at Tarannon, consists of evenly bedded grits and shales (Aberystwyth or Cwmystwyth Grits), and although it is possible that they represent part of the Talerddig Grits, their exact equivalence has not been established. The grits are well developed in the axial region of the Central Wales Syncline and are also finely displayed

in the cliffs north and south of Aberystwyth. In Cwmystwyth the grits are followed by pale unfossiliferous shales, lithologically similar to the Dolgau Mudstones of the Tarannon area.

Wenlock Series.—In the Central Wales Syncline no Silurian rocks younger than the Llandovery have been detected, and the absence of the Wenlock and the higher Ludlow Series is a striking testimony to the enormous denudation which the region has undergone. The Wenlock Series is confined to a belt ranging southwards from Tarannon to near Builth and overlies the Upper Llandovery with complete conformity. From the latter town south-westwards to Llanarthney the rocks occupy a narrow strip of country lying on the south-eastern flank of the Towy Anticline (Fig. 13). Farther west they are again seen in several of the Silurian inliers in Pembrokeshire, the most notable sections being those of Marloes Bay and Wooltack Park. South of the Coalfield they are present in the Rumney Anticline at Cardiff.

In the northern outcrop the beds consist of dark grey shales, flags, and mudstones. They contain graptolites, the chief members of the fauna being species of *Cyrtograptus* and *Monograptus* occasionally associated with brachiopods and trilobites. Near Builth, where Dr. G. L. Elles has recognized six graptolite zones, the formation is over 1,600 ft. thick. The beds were obviously deposited along the margin of a sinking area and in consequence there is a marked overstep of higher zones on to lower.

Towards the south-west the formation is progressively overstepped by the Downton Series. Near Llandeilo only 200 ft. of mudstones with *Monograptus flemingi* are present. At Llanarthney they pass laterally into limestones and shales containing *Orthis* (*Platystrophia*) *biforata*, *Delthyris elevata*, *Bumastus* [*Illaenus*] *barriensis*, and *Dalmanites* [*Phacops*] *caudatus* ; the calcareous beds may represent the Woolhope Limestone on the Welsh Borders and mark the beginning of the shelly facies prevalent in South-west Pembrokeshire.

This facies is well displayed in the inliers of Winsle, Lindsway Bay, Wooltack Park, Marloes Bay, and Freshwater East south-east of Milford Haven. In Marloes Bay the Beds consist of some 300 ft. of mudstones with calcareous bands (Coraliferous Series of De la Beche) which are considered to be the equivalent of the Woolhope Limestone ; they contain crinoids, corals, brachiopods, and trilobites. The common species are *Palaeocylus porpita*, *Favosites gothlandicus*, *Delthyris elevata*, *Calymene blumenbachi*, *Bumastus* [*Illaenus*] *barriensis*, and *Dalmanites* [*Phacops*] *weaveri*. The higher beds like the overlying Ludlow are sandy and in the absence of fossils the upper limit of the Series is difficult to determine. At Wooltack Park the Wenlock rocks appear conformably to succeed the shales with *Stricklandia lirata*, but in the inland sections they overstep the Upper Llandovery on to the Skomer Volcanic Series.

In the Rumney inlier at Cardiff a sandy shelly facies of the Wenlock is also developed, the lithological characters of the beds suggesting the proximity of a shore-line ; the rocks include greenish shales and sandstones, some of which show ripple-marks. The most distinctive band is the Rumney Grit ; it has yielded the lamellibranchs *Ctenodonta* and *Grammysia cingulata* and the problematical seed-like body *Pachytheca*.

Ludlow Series.—Ludlow rocks are also confined to a narrow strip of country between Builth and Llandeilo, but the outcrop is of variable width, the beds being overstepped by the Downton Series, beneath which they disappear. In Pembrokeshire they follow the Wenlock at Lindsway Bay, Marloes Bay,

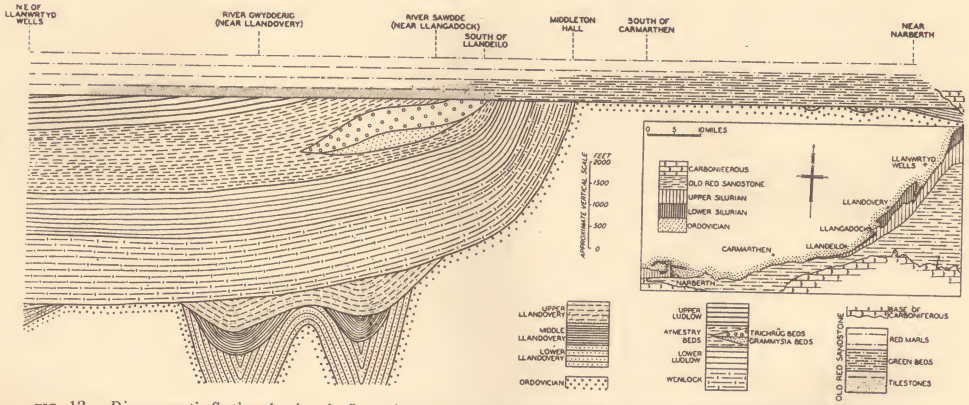

FIG. 13.—*Diagrammatic Section showing the Succession of Silurian and Lowest Old Red Sandstone Strata along the South-Eastern Flank of the Towy Anticline.*

Wooltack Park, and are present south of Milford Haven at Freshwater East and Freshwater West. The Series also outcrops in the Rumney anticline and in the Usk inlier of the Welsh Borderland.

In the Builth district a twofold division can be made, the lower group being correlated with the Lower Ludlow and the Aymestry Limestone. The Lower Ludlow beds comprise about 750 ft. of dark graptolitic shales, flags, and mudstones, and succeed the Wenlock without any appreciable change in lithology; the junction, however, is marked by the incoming of graptolites of the type of *Monograptus colonus* and by the disappearance of species of *Cyrtograptus*. Near Builth most of the graptolite zones have been recognized by Dr. G. L. Elles. When the beds are traced to the south and east they become more sandy, and some of the higher zones are represented in the thick group of sandstones, sandy shales, and occasional limestones, all in shelly facies. The occurrence of *Monograptus leintwardinensis*, however, suggests that the higher portion is the sandy equivalent of the Aymestry Limestone. Brachiopods are conspicuous elements of the fauna, and include *Atrypa reticularis*, *Gypidula galeata*, *Whitfieldella didyma*, *Dayia navicula*, and *Chonetoidea grayi*. Farther to the south-west a littoral phase is developed. It is best seen in the Sawdde Gorge at Pont-ar-llechau, where dark purple and grey sandstones and shales (Grammysia Beds) with *Chonetes striatellus*, *Wilsonia wilsoni*, and *Holopella gregaria* are followed by 600 ft. of pebbly grits, sandstones, and marls (Trichrûg Beds) (Figs. 11 and 13). The latter appear near Horeb Chapel, and form the central ridge of Trichrûg. They are overlain by greenish shales containing *Chonetes striatellus*, *Dayia navicula*, and *Beyrichia lauensis*. The Upper Ludlow is at least 600 ft. thick, and, in the Builth district, consists of green shales and calcareous gritty bands with *Chonetes striatellus*, *Orthis* (*Dalmanella*) *lunata*, *Camarotoechia nucula*, *Orthonota amygdalina*, *Holopella conica*, *Beyrichia torosa*, and other typical forms.

In South-west Pembrokeshire Ludlow rocks are mainly of arenaceous facies like the uppermost Wenlock, and the base is difficult to define; but at Wooltack Park, Marloes Bay, and Lindsway Bay they include about 2,000 ft. of greenish sandstones and mudstones. The fauna is scanty and is confined to thin bands containing brachiopods, lamellibranchs, and trilobites; amongst the last is the characteristic species *Homalonotus johannis*. At the south end of Marloes Bay, Ludlow beds are followed by the Old Red Sandstone.

At Freshwater West the formation is also sandy and oversteps on to Llanvirn shales. At this locality the best section is to be seen on the south side of the bay, where about 250 ft. of greenish sandstones and shelly mudstones with calcareous bands are exposed. Higher beds are found on the north side of the bay and it is possible that the equivalents of the Aymestry Limestone are represented below the unconformable base of the Old Red Sandstone. At Freshwater East, where in the past many fossils have been found, the unconformity is not so marked, as the Ludlow rocks, with a conglomeratic base, rest discordantly on Wenlock mudstones.

In the Rumney fold the Series, though not well exposed, appears to be represented by flaggy sandstones, mudstones and shales. The highest bed is a brownish grit full of fish-remains, including spines of *Onchus tenuistriatus*. It may represent the Ludlow Bone Bed at the base of the Downton Series.

Intrusive Rocks of Silurian Age.—In the Wells district of Central Wales there are several basic intrusive rocks which are believed to be of Silurian or post-Silurian age. They are chiefly porphyritic dolerites containing albitized

feldspars and pseudomorphs after olivine, and have invaded black Caradoc shales at Llanwrtyd and at Baxter's Bank near Rhayader. Several sills of diabase occur at Builth and east of Gelli Hill, Llandrindod Wells; near the latter locality the intrusive rock is in contact with a limestone yielding *Stricklandia lirata*. It has been suggested by H. G. Smith that all these intrusions belong to the same period, and may be 'brought into line with those of the Shelve area, where Professor Watts has shown that the dolerites come into contact with and somewhat alter the *Pentamerus* limestones.'

Minerals.—Lead, zinc, copper, and iron ores are present in the Llandovery rocks of Central Wales. These ore-bodies are found in fissures, faults, or lodes which generally run obliquely across the strike of the beds, and it is probable that the occurrence of some of the minerals may be attributed to the Caledonian orogeny. Small quantities of gold also occur in quartz lodes in rocks of the same age; some authorities claim that the Romans worked the metal at Ogofau, near Llanpumpsaint.

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VI. THE OLD RED SANDSTONE

BEFORE THE CLOSE of Ludlow times a great part of Britain was affected by powerful earth-movements which gave rise to a series of folds with a north-east to south-west or Caledonoid trend. In South Wales these movements, which, as O. T. Jones has suggested, may have commenced in late Valentian times, at first brought about a general shallowing of the Lower Palaeozoic geosyncline ; then followed emergence of that part of the basin situated in Central Wales which, as already mentioned, later formed St. George's Land (Fig. 13). South-east and south of this land lay a new basin, which included an indeterminate part of South Central Wales and the counties of Devon and Cornwall ; but it is possible that the Welsh part was to some extent separated by a barrier running approximately along the Bristol Channel. The basin extended eastwards from Central Wales into the West Midlands of England, and on this account the depression has been termed the Anglo-Welsh cuvette. It was in this gulf that the sediments accumulated during the long period between Ludlow and Carboniferous times : owing to the proximity of land the bulk of the deposits in South Wales are deltaic, fluviatile and lacustrine, differing from those laid down in the sea covering Devon and Cornwall.

At first the deposits were associated with a marine fauna, relics of the Silurian life-forms, but these gradually disappeared as the sea was replaced by fresh water brought in by rivers flowing southwards off St. George's Land ; the sediment, much of it red with ferric oxide, was laid down in shallow water, and formed thick masses of red marls, sandstones, breccias, and conglomerates. Frequently these were interbedded with green and grey sandstones and mudstones, in which the absence of a red colour is believed to be due to the reduction or solution of ferric oxide by some organic agency, probably vegetable matter. Beds of limestone were also formed ; those known as cornstones are of inorganic origin, and are either concretionary or conglomeratic with broken nodules of penecontemporaneous 'race'. It is probable that they indicate periods of aridity during which sheets of water charged with lime were evaporated.

After a long period of continuous sedimentation, deposition was interrupted by powerful uplift and violent earth-movement, the main Caledonian folding or orogeny, during which St. George's Land was again elevated, and much of the gulf raised into a low-lying peneplain. The interval, during which the Middle Old Red Sandstone of Scotland was being deposited, was a period of great erosion, so that in many places the succeeding sediments of the Upper Old Red Sandstone rest unconformably on the Lower Old Red Sandstone.

On renewed subsidence the area of deposition, which had persisted over south-western England, again extended to South Wales and a second epoch of deposition commenced. The first-formed of the newer beds spread across those of the older epoch gently and fairly uniformly ; consequently basal conglomerates are rare or absent, and as the overlap of basal members is inconspicuous it is difficult to demonstrate in the field the stratigraphical break caused by the Caledonian movements.

The conditions controlling sedimentation during the period of the Upper Old Red Sandstone were similar to those of the first. Red marls, sandstones, and

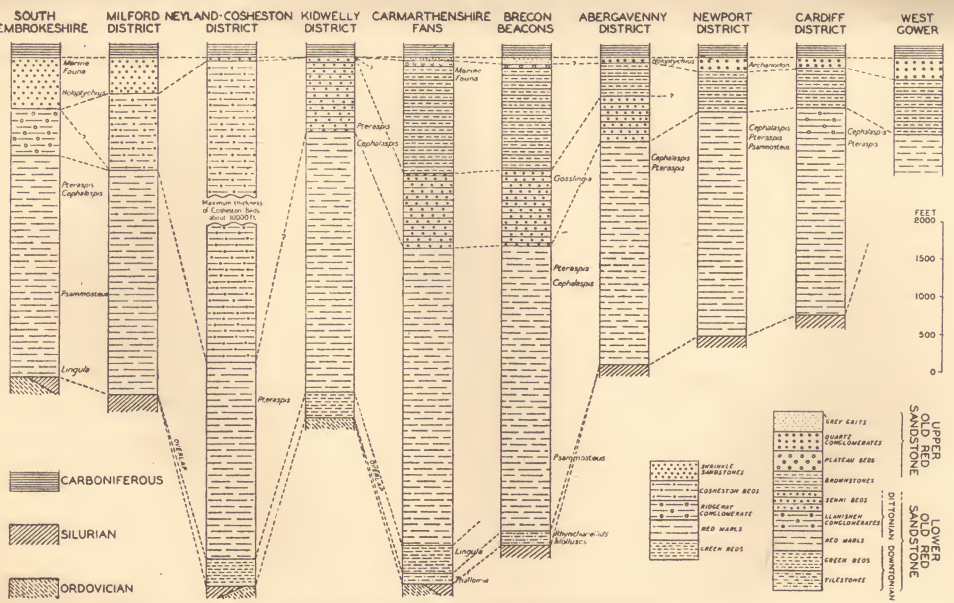

FIG. 14.—*Comparative Sections of the Old Red Sandstone.*

breccias were laid down, but no grey micaceous flags. The different configuration of the basin, however, had important effects. Elevation of St. George's Land had brought the shore-line farther to the south, and consequently the deposits are marginal in character. As a rule sediments are thin and variable, but in South Pembrokeshire they may attain a thickness of 1,500 feet.

Towards the close of the epoch the sea invaded the western end of the region, bringing in a marine fauna. The species are identical with those characteristic of the Upper Devonian rocks (Marwood Beds) of North Devon, and thus afford proof of the continuity of the basin across the Bristol Channel. Throughout South Wales to the east, however, the deposits are unlike those of Pembrokeshire and appear to have been part of a great delta of a river flowing southwards down the Welsh Borderland, and only at one locality have marine fossils been found in them. Finally, the Carboniferous sea entered the basin and spread on to the margin of St. George's Land.

Some of the fossils of the Old Red Sandstone are of great interest, since they afford evidence of the establishment of vascular land plants and of fishes, though rare examples of earlier forms are known from Silurian rocks. During Lower Old Red Sandstone times jawless ostracoderms, comparable with present-day lampreys, reached their acme and displayed varied and complex types, while in the Upper Old Red Sandstone true fishes of comparatively advanced type appeared. The plants, though abundant at certain horizons, are very fragmentary ; material obtained from the Downton rocks in South Wales and in England has been studied by W. H. Lang, who has given an account of the flora in a comprehensive monograph.

The various subdivisions of the Old Red Sandstone are shown on Fig. 14. Considerable uncertainty exists regarding the classification of the Downton Series, and according to the recent practice of the Geological Survey the rocks are retained in the Silurian. The important investigations of the faunas by Wickham King, however, have led him to suggest that not only the Downtonian but also the overlying Ditton Series should be placed in the Silurian. On the other hand, Stamp, Robertson, and Straw have placed the summit of the Silurian immediately below the Ludlow Bone-Bed which lies at the base of the grey Downtonian in the Welsh Borderland. They have pointed out that the fauna undergoes a marked change at this horizon, notably in the establishment of an important new element, the fish-like chordates. On this view the Downton mollusca are survivors of an old fauna, and are of doubtful chronological value.

Although the Ludlow Bone-Bed is absent in the Builth area, other evidence afforded by the Downton Series in South Wales demonstrates the suitability of its base as marking the upper limit of the Silurian System. Throughout the region, the Downtonian is either unconformable to all older rocks, or is separated by a break accompanied by an abrupt change in the character of the sedimentation. In view of the general unconformity, therefore, and of the unbroken cycle of sedimentation that followed it, stratigraphically the whole of the deposits of the cycle could be separated from the Ludlow Series as part of a distinct system. The fauna and flora of the Downton Series, the Ditton Series, and the Cosheston Series in our opinion justify their reference to a single formation, the Lower Old Red Sandstone.

LOWER OLD RED SANDSTONE

Downton Series.—The Downton Castle Sandstones of Shropshire are represented farther south by grey, green, and yellow micaceous flaggy sandstones (Tilestones) and grits and brown rottenstones, in all about 150 ft. thick. These are known as the Grey Downton Series. They are of local development in the region, being confined to Breconshire and Carmarthenshire, and were obviously deposited under conditions very different from those which governed the accumulation of the underlying Ludlow rocks. They are well exposed at Pont-ar-llechau in the Sawdde Valley, near Llangadock, where the Tilestones rest on Aymestry Beds ; in turn they are overlapped by or pass laterally into the marls of the Red Downtonian (Fig. 13).

The fauna of the Tilestones is scanty, and is restricted to a few species of brachiopods, lamellibranchs, gastropods, and ostracods, including such forms as *Orthis* (*Dalmanella*) cf. *lunata*, *Camarotoechia nucula*, *Grammysia extrasulcata*, *Modiolopsis complanata*, *Platyschisma helicites*, eurypterids, and *Kloedenia wilckensiana*. Fish-remains, which gave rise to bone-beds in the Welsh Borderland, are absent, though possibly represented in the Rumney section at Cardiff. At Capel Horeb east-north-east of Llangadock *Thallomia breconensis*, the earliest vascular plant showing well-preserved stomata, has been isolated with great skill by Heard and J. F. Jones from an interbedded lens of shale in the Tilestones.

In the lowest muds of the succeeding Red Downtonian the marine fauna is almost wholly absent, though in places a few ostracods (*Leperditia*), eurypterids, hingeless brachiopods, and the molluscs *Modiolopsis* and *Platyschisma* persist through a small thickness. *Modiolopsis*, however, has been recorded by Wickham King in red marls some hundreds of feet above the base of the subdivision in Pembrokeshire. On the other hand, the free swimming fish (ostracoderms) entered and are the most abundant fossils throughout the Ditton Series. The basal beds of the Red Downtonian have yielded *Hemicyclaspis* [*Cephalaspis*] *murchisoni*, and the so-called *Psammosteus* Limestone in the upper part of the subdivision contains *Phialaspis*, a genus which includes shields formerly called *Psammosteus anglicus* and *Cyathaspis symondsi*.

Ditton Series.—The red marls of this subdivision include bands of soft dull red and green micaceous sandstone. Conglomeratic cornstone also occurs on several horizons.

The Series is distinguished from the Red Downtonian by the establishment of *Pteraspis*. The common species, *Pteraspis rostratus* and *P. crouchi*, enter at the *Cephalaspis* Sandstone which lies at the base of the formation. Of importance is a variety of *Pteraspis* (*Rhinopteraspis*) *dunensis*, a large ostracoderm widespread in the upper part of the Lower Devonian on the Continent. It has been figured by E. I. White from a bed of red marl, known from its finder, A. L. Leach, as Leach's Fish Bed, at Swanlake Bay, Pembrokeshire, where it is associated with a coccosteid (*Phlyctaenaspis ?*). More recently, White has recorded *P. dunensis* from rocks referred to the Senni Beds of Crickhowell in Breconshire.

The Red Conglomerate Group.—These pebble-beds are known only in Pembrokeshire south of Milford Haven (the Ridgeway Conglomerates), and near Cardiff (the Llanishen Conglomerates). As has been emphasized by A. H. Cox, the conglomerates are similar in the two areas and consist of pebbles of sandstone, quartzite, and white quartz in a red marly or sandy matrix. The

interbedded strata resemble the underlying red marls. Concretionary cornstones are probably more abundant among the Ridgeway Conglomerates than in the Dittonian below.

The conglomerates attain a thickness of 1,200 ft. in Pembrokeshire, but are absent along the outcrop north of the Coalfield where the red marls of the Ditton Series pass up into the Senni–Cosheston Beds, apparently without a break. The restriction of the conglomerates to the southernmost outcrops suggests derivation of the pebbles from some source other than the northerly area from which, as Heard and Davies have shown, the sediments of the normal sequence have been derived. The conglomerates contain no indigenous fossils, but fossils have been found in a few of the quartzite pebbles. Some of them contain broken shells of horny brachiopods, while one pebble has yielded an unidentifiable trilobite. According to Stubblefield the fossiliferous pebbles are lithologically similar to those of Grès de May aspect found in the Triassic Budleigh Salterton Pebble-Bed. Wherever the source of the pebbles may have lain, the large size and incompletely worn character of some of them suggest that it was at no great distance from the present outcrops. It seems difficult to avoid the conclusion that a land ridge extended along the site of the Bristol Channel.

Cosheston Beds.—In the type area in Pembrokeshire this group attains a thickness of about 10,000 ft. at a maximum, but it is not known in the outcrops south of Milford Haven, being overstepped by the Upper Old Red Sandstone. It consists below of green micaceous sandstones with bands of green and grey marl and grey conglomeratic cornstones, and above of breccias largely composed of igneous debris.

Along the flanks of the South Wales Coalfield the approximate equivalents of the Cosheston Beds seem to be the Senni Beds, consisting of sage-green and dull red sandstones and micaceous flags. They are generally unfossiliferous, but at Pen-y-gau near Kidwelly, at about 150 ft. above the base, *Pteraspis* has been found in greater abundance than at any other locality or horizon in South Wales. According to White the specimens belong to a new species, *P. dixoni*. This, the last appearance of *Pteraspis* in South Wales, would imply that the lowest part of the Senni Beds is locally of Dittonian age. The Senni Beds are overlain by the Brownstones, an unfossiliferous group of bright red marls and brown sandstones with some conglomeratic layers. Towards the eastern and south-eastern flanks of the Coalfield the typical lithology of the Senni Beds ceases to be recognizable, probably by lateral passage, and the red marls of the Dittonian are followed immediately by red sandstones of Brownstone type.

In the Cosheston Beds and the Senni Beds the remains of vascular plants have been found by W. H. Lang to be not uncommon; some with sporangia have been described already by Heard under the name *Gosslingia*.

UPPER OLD RED SANDSTONE AND UPPER DEVONIAN

No representatives of the Middle Old Red Sandstone are known with certainty to occur in South Wales, and in many places the Upper Old Red Sandstone rests with unconformity upon the beds beneath. It consists of a varied group of sandstones, grits, and conglomerates that are mostly local and impersistent in development. In Pembrokeshire the beds comprise the Skrinkle Sandstones; on the flanks of the South Wales Coalfield they include the Quartz

Conglomerates and the Grey Grits together with at least the uppermost Brownstones. In Pembrokeshire particular interest attaches to the occurrence of marine beds ; they link the top of the Skrinkle Sandstones with the Upper Devonian.

Skrinkle Sandstones.—The lowest part of this group consists mainly of sandstones and fine breccias ; these are succeeded by breccias, conglomerates, and red marls locally interbedded towards the top with mudstones and thin limestones with marine fossils. Many of the breccias contain material derived from igneous rocks showing a general similarity to those of the Pre-Cambrian and Lower Palaeozoic formations of North Pembroke. The beds increase in thickness in a southerly direction, from 413 ft. at West Angle Bay to over 1,000 ft. at Freshwater West.

In Pembrokeshire the characteristic scales of *Holoptychius*, a fringe-finned ganoid fish, and some bony armour, probably of an asterolepid fish, have been obtained from the base of the Skrinkle Sandstones, but higher in the sequence the only animal-remains known are from the marine intercalations. As was shown by Salter, this marine fauna closely resembles that of the Marwood Beds of Devon. It includes abundant specimens of *Ptychopteria damnoniensis* and other lamellibranchs, hinged brachiopods (*Spirifer verneuili* and rhynchonellids), and crinoids, together with palatal teeth of ray-like fish, the ancestors of families which, at most places, appear first at the base of the Carboniferous.

Plant-remains are frequent in the higher part of the Skrinkle Beds but are fragmentary. They include a woody stem (*Bothrodendron ?*) and a fern-like leaflet (*Sphenopteris ?*). At two horizons they have given rise to laminae of coal.

Brownstones.—The lowest beds of the Brownstones follow the Senni Beds without a recognizable stratigraphical break and at the junction there is an alternation of red and green strata. They thus probably belong to the Lower Old Red Sandstone. Nevertheless, although continuity of deposition appears to be complete in the Brownstones, their uppermost beds have yielded in one small exposure in Breconshire a fauna of marine fossils, including *Spirifer verneuili*, proving an Upper Devonian age. It is therefore possible that some part of the Middle Old Red Sandstone may be represented within the Brownstones Series.

In Carmarthenshire and Breconshire the uppermost beds of the Brownstones are coarse red quartzitic conglomerates, the Plateau Beds, so named because they give rise to the table-top scenery of the Brecon Beacons (Pl. IIA).

Quartz Conglomerates and Grey Grits.—These beds, 200 to 300 ft. thick, are well displayed along the eastern and north-eastern flanks of the South Wales Coalfield. They are coarse grey, yellow, and red sediments with pebbles largely derived from a land-mass chiefly of Pre-Cambrian rocks to the north. They are practically unfossiliferous, though *Holoptychius* has been recorded from them near Crickhowell, and the freshwater mussel *Archanodon jukesi* from near Newport. In the Merthyr district the group appears to transgress the Plateau Beds westwards on to lower horizons of the Brownstones. In their turn the grits are overlapped or overstepped north of Ammanford by the overlying Carboniferous. In Gower sandstones of Brownstone type are followed by red and white quartz conglomerates presumably of the same age as those of the North Crop.

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VII. THE CARBONIFEROUS SYSTEM

CARBONIFEROUS LIMESTONE OR AVONIAN SERIES

THE MARINE DEVONIAN intercalations in the Upper Old Red Sandstone of Pembrokeshire marked the beginnings of a general subsidence of the southern flanks of St. George's Land, when the sea, previously largely confined to the area south of the (present) Bristol Channel, transgressed northwards and flooded the freshwater Old Red Sandstone cuvette. The rocks succeeding the Old Red Sandstone therefore were deposited under marine conditions and, although shallow-water in origin, largely consist of thick beds of pure limestone formed in great measure from the skeletons of marine animals (Fig. 15). They are called the Carboniferous Limestone or Avonian (Dinantian) Series, and differ notably from the marls, sandstones, and conglomerates beneath.

The transgression of the Carboniferous sea followed the deposition of the Upper Old Red Sandstone without any marked intervening earth-movement, there being in places (particularly in South Pembrokeshire) a thin transitional series of strata displaying both Devonian and Avonian affinities. At all localities where they are seen in contact the Avonian rocks therefore rest conformably on the Skrinkle Sandstones and the Quartz Conglomerate Group. Being the deposits of a transgressive sea, however, they overlap the Upper Old Red Sandstone in places and extend unconformably on to older strata. Thus between Llandebie and Kidwelly the Carboniferous Limestone Series progressively oversteps the outcrops of the Brownstones, and at Kidwelly comes to rest on the Senni Beds. Along the North Crop in Pembrokeshire also this unconformity is well displayed, the Avonian rocks overstepping on to the Red Marls.

Stratigraphical Succession.—Cropping out in the Armorican folds south of the Coalfield, and forming a narrow belt along the North Crop, the Carboniferous Limestone Series is most thickly and completely displayed in South Pembrokeshire, Gower, and the Vale of Glamorgan, where the succession is broadly divisible into the three lithological groups of Lower Limestone Shales, Main Limestone, and Upper Limestone Shales. Essentially these divisions mark the establishment, the main development, and the conclusion of the marine cycle represented in the Lower Carboniferous succession, the pure limestone phase being preceded and followed by beds containing a large proportion of terrigenous material. These divisions, however, do not hold over the whole of South Wales, and Dixon and Vaughan have shown that in detail the strata are more precisely subdivided, on the basis of the fossil sequence correlated with variations in the type of limestone, into the following zones :—

Upper Avonian	Dibunophyllum Zone (D) Main Seminula Zone (S_2) Upper Caninia Zone (C_2S_1)
Lower Avonian	Lower Caninia Zone (C_1) Zaphrentis Zone (Z) Cleistopora Zone (K)

Cleistopora Zone.—This zone is approximately conterminous with the Lower Limestone Shales, a series of deposits consisting of alternations of shales and thin limestones, the calcareous beds being subordinate to the argillaceous. Many of

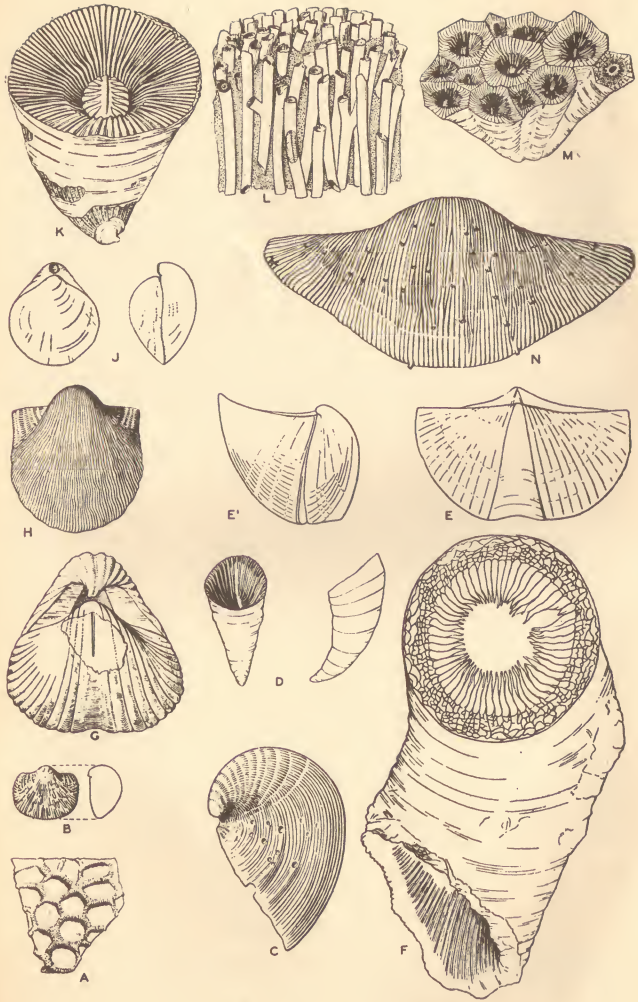


FIG. 15.—*Carboniferous Limestone Fossils.*

the beds of limestone are impure and often weather to rottenstone. Occasional beds are oolitic ; some are sandy, quartzitic, or even conglomeratic. The whole series bears evidence of accumulation in shallow water into which a considerable amount of terrigenous material was being brought.

The only corals found in the zone are specimens of *Vaughania* [*Cleistopora*] *vetus* and occasional zaphrentids. Brachiopods, on the other hand, are common and include *Spirifer tornacensis*, *Syringothyris cuspidata*, *Spiriferina octoplicata*, *Cleiothyridina* [*Athyris*] *roissyi*, *Hustedia carbonaria*, *Camarotoechi amitcheldeanensis*, *Productus* (*Avonia*) *bassus*, and species of *Chonetes*. The lowest beds, though not greatly differing in lithology from those above, have a more restricted fauna and appear to have been formed under lagoonal conditions ; they constitute a Modiola phase characterized by the lamellibranchs *Modiola*, *Myophoria*, *Ctenodonta*, *Grammatodon*, and *Sanguinolites* ; other common fossils are annelids and ostracods.

Although the Lower Limestone Shales show little lateral change in lithology, they differ considerably in thickness in the various outcrops. Thus in the Bosherston district they are at least 600 ft. thick, decreasing to 450 ft. in the Pembroke Syncline (at Skrinkle, where they show complete transition from the underlying Devonian Skrinkle Sandstones), and to about 300 ft. near Carew. In Gower they are about 500 ft. thick, but in the Vale of Glamorgan they decrease from 350 ft. near Bridgend to 250 ft. in the Taff Valley and to 120 ft. in the Ebbw Valley, the group then suffering little diminution northwards to the North Crop near Abergavenny and Llangattwg.

Zaphrentis Zone.—Typically, as in south-western Gower and in South Pembrokeshire, the highly fossiliferous crinoidal limestones of this zone mark the beginning of the zaphrentid-phase deposits that continue into the overlying Lower Caninia Zone, and are not easily distinguished from the higher beds. Cherts, however, are common at certain levels. In eastern Gower the zone becomes highly dolomitic and merges into the Laminosa Dolomites above. Similarly, in the Vale of Glamorgan there is progressive dolomitization as the beds are traced eastwards, and between the Taff and Ebbw valleys they consist wholly of crystalline dolomites and dolomitic mudstones—rock types that also characterize the zone on the North Crop near Llangattwg. The dolomitization is accompanied by progressive decrease in thickness, from over 500 ft. in south-western Gower to 300 ft. in eastern Gower and the Bridgend district, to about 150 ft. in the Ebbw Valley, and to less than 30 ft. near Llangattwg (where, as in the Ebbw Valley, the zone is not readily separable from the Lower Caninia Zone).

The fossils of the Zaphrentis Zone are closely similar to those of the Lower Caninia Zone, but no species of *Caninia* is present, the only important corals being the zonal forms *Zaphrentis omaliusi*, *Z. koninckı*, and *Z. vaughani*, and species

FIG. 15.—*Carboniferous Limestone Fossils.*

(All natural size.)

A, *Vaughania* [*Cleistopora*] *vetus* Smyth ; **B**, *Productus* (*Avonia*) *bassus* Vaughan ; **C**, *Productus* (*Dictyoclostus*) *vaughani* Muir-Wood ; **D**, *Zaphrentis koninckı* Edwards and Haime, two views ; **E**, *Syringothyris cuspidata* (Martin), mut. *cyrtorhyncha* North, two views ; **F**, *Caninia gigantea* Michelin ; **G**, *Davidsonina* [*Cyrtina*] *carbonaria* (McCoy) ; **H**, *Productus* (*Linoproductus*) *corrugatohemisphericus* Garwood ; **J**, *Composita* [*Seminula*] *ficoidea* (Vaughan), twovi ews ; **K**, *Dibunophyllum* cf. *turbinatum* (McCoy) ; **L**, *Lithostrotion junceum* (Fleming) ; **M**, *Lonsdaleia floriformis* (Martin), forma *crassiconus* (McCoy) ; **N**, *Productus* (*Gigantella*) *latissimus* J. Sowerby.

of *Michelinia*. Brachiopods, including *Spirifer tornacensis*, are abundant especially in the shale bands.

Lower Caninia Zone.—In south-western Gower and the Bridgend district, this zone consists of three lithological divisions :—

iii. Caninia Oolite. This rock, sharply distinguished from the lagoon phase deposits or the crinoidal limestones of the zone above, consists of a fine close-grained pure white oolite, very well jointed, not greatly differing from the Seminula Oolite ; like the latter it shows evidence of having been deposited in shallow water in the occurrence of false-bedding and contemporary brecciation.

ii. Laminosa Dolomites. These are dark grey or buff finely crystalline dolomites with interbedded crinoidal limestones. They seem to have formed penecontemporaneously while the deposits were still under the influence of the Avonian sea, and to be due in part to the leaching of calcite from more normal limestones.

i. Crinoidal ' standard ' limestones. These beds are similar to those of the Upper Caninia Zone, and consist of thin-bedded crinoid limestones (sometimes of ' petit granit ' type) alternating with calcareous mudstones and shales.

Fossils are abundant in the lowest division, and are members of a typical zaphrentid phase including species of *Zaphrentis*, *Caninophyllum* [*Caninia*] *patula*, and tabulate corals ; the brachiopods are represented by productids and chonetids, *Spirifer tornacensis*, and *Tylothyris laminosa*. The Laminosa Dolomites are almost unfossiliferous, but in large measure this is probably due to the destruction of fossils in the process of dolomitization, the original rocks apparently having been crinoidal limestones comparable with the fossiliferous beds beneath. The Caninia Oolite, like the Seminula Oolite, contains few fossils ; of these primitive clisiophyllid corals (*Koninckophyllum*) and *Michelinia* are important, while at Three Cliffs Bay in Gower the Oolite has yielded the goniatites *Muensteroceras* cf. *inconstans*, *Pericyclus kochi* and *Prolecanites* cf. *discoides*.

In the Bosherston outcrops in South Pembrokeshire the threefold lithological division breaks down, the greater part of the zone consisting of a succession of alternating shales and limestones with a rich zaphrentid-phase fauna ; the whole is with difficulty separated from the overlying crinoid limestones of the Upper Caninia Zone, there being no development of the Caninia Oolite. In these outcrops, however, Dixon has described the occurrence of peculiar magnesian rocks, the ' reef ' dolomites. In these beds there is a complete absence of bedding planes and they appear to be contemporaneous mounds formed by the accretion of dolomite crystals on crinoids and on the flakes and fans of Bryozoa ; they are essential bryozoan reefs, and are almost devoid of other fossils. They formed contemporary elevations on the floor of the Avonian sea, and the neighbouring sediments, consisting of thin-bedded limestones and shales, are wrapped round, and interdigitate with the flanks of, the reefs. In many characters the reefs are similar to those of the knolls at Clitheroe and the Waulsortian knolls of Belgium.

In the eastern outcrops along the South Crop between the Bridgend district and the Ebbw Valley, Dixey and Sibly have shown that the facies of the Laminosa Dolomites encroaches upon the overlying and underlying strata (Fig. 17), and near Cardiff and Newport the whole of the zone is an indivisible group of crystalline magnesian rocks with only a few interbedded fossiliferous crinoidal limestones and with some beds of dolomite mudstone indicative of lagoon-phase conditions. At the same time the zone is much reduced in thickness, from about 500 ft. to 600 ft. in Gower and near Bridgend to about 350 ft. in the Ebbw Valley (where, however, the zone is not readily separated from the underlying dolomites of the Zaphrentis Zone). On the North Crop between

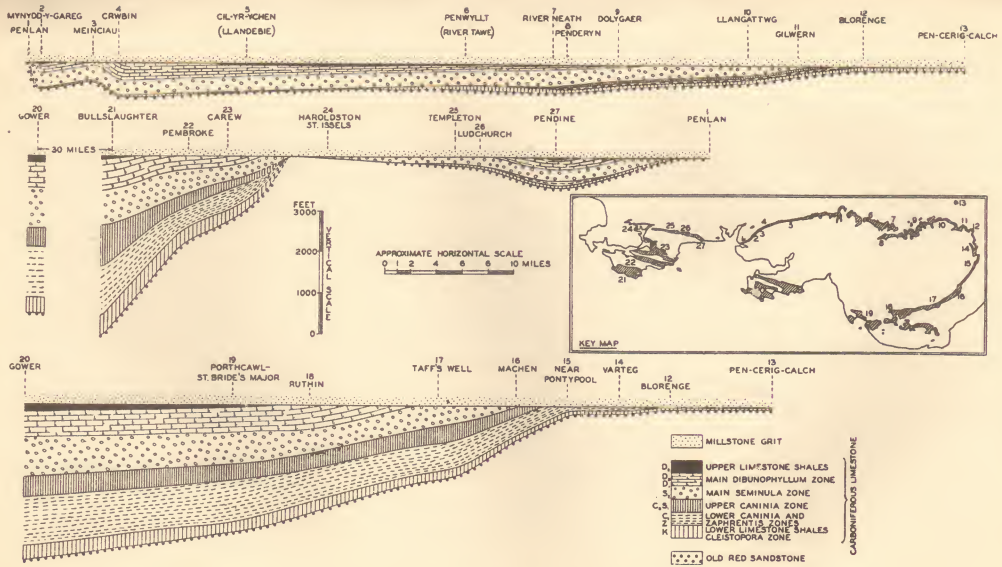


FIG. 16.—*Sections showing Lateral Changes in the Carboniferous Limestone.*

Llangattwg and the Vale of Neath there is a further great attenuation, the Zaphrentis and Lower Caninia Zones together being at a maximum only 80 ft. thick; nevertheless, the Caninia Oolite there retains its original structure. In Pembrokeshire also there is a comparable reduction in thickness as the zone is traced northwards, from about 500 ft. near Bosherston to about 400 ft. in the Pembroke Syncline, and to little more than 200 ft. near Tenby. This thinning is likewise accompanied by an encroachment of the magnesian facies, particularly upon the underlying crinoid limestones; nevertheless, the Caninia Oolite, though more or less dolomitic in the lower beds, retains its individuality even in the northernmost outcrops before being overstepped by the Upper Avonian.

Upper Caninia Zone.—Typically, this zone consists of highly fossiliferous 'standard' limestones, many crinoidal but some oolitic or porcellanous. The upper beds are more oolitic than the lower and merge upwards without any marked break into the thick oolites of the Seminula Oolite. Many of the lower strata are thin-bedded and consist of alternations of coarse crinoidal limestones and dark grey calcareous shales crowded with fossils; in the southernmost sections of Pembrokeshire (the Bosherston–Linney Head district) such fossiliferous limestones (a zaphrentid phase) persist to the top of the zone and even into the basal beds of the overlying Seminula Zone; they seem to indicate deposition along the inner margin of the 'blue-mud belt'. In the southern outcrops of Pembrokeshire, in south-western Gower, and in the Bridgend district of the Vale of Glamorgan there is an abrupt but otherwise normal junction with the Caninia Oolite beneath, but elsewhere, as at West Williamston, in eastern Gower, and in the Miskin district of the Vale of Glamorgan, the upper surface of the Caninia Oolite is uneven and slightly eroded, and is followed by a thin group of shales and calcite mudstones that locally are the first-formed deposits of the Upper Caninia Zone; these beds have been considered by Dixon to indicate deposition under extremely shallow-water conditions characteristic of a lagoonal environment—they constitute a lagoon phase.

Fossils are exceedingly abundant in the crinoidal limestones. They include the corals *Caninia gigantea*, *C. cornucopia*, and species of *Zaphrentis* that are found throughout the zone; in the upper part *Lithostrotion martini* and *L. basaltiforme* come in; a species of *Palaeosmilia* is also common; the tabulate corals are represented by *Michelinia grandis* and species of *Syringopora*. Many brachiopods occur, the chief being productids, *Chonetes destinezi*, *Athyris expansa*, spiriferids, and species of *Composita*. Gastropod beds recur at intervals throughout the zone; they are crowded with species of *Bellerophon*, *Euomphalus*, *Zygopleura*, *Loxonema*, and *Aclisina*; associated with the gastropods are specimens of *Conocardium*. A single horizon in the lower part of the zone in Gower has yielded well-preserved goniatites referable to *Muensteroceras* and *Merocanites* [*Prolecanites*]; they are associated with nautiloid cephalopods. In the basal lagoon phase fossils are mostly rare, the only abundant forms being ostracods.

The maximum thickness of the zone exceeds 1,000 ft. in southern Pembrokeshire, but in the Pembroke Syncline it is at most about 400 ft. In Gower also, and in the west of the Vale of Glamorgan, it is no more than about 600 ft., though the lithology is much the same as in southern Pembrokeshire. Traced eastwards from the Bridgend district along the South Crop to the Taff and Ebbw valleys, the zone becomes greatly reduced in thickness, being some 200 ft. near Risca. At the same time there is a great change in lithology, the crinoidal beds of the west being replaced by a series of unfossiliferous dolomite mudstones

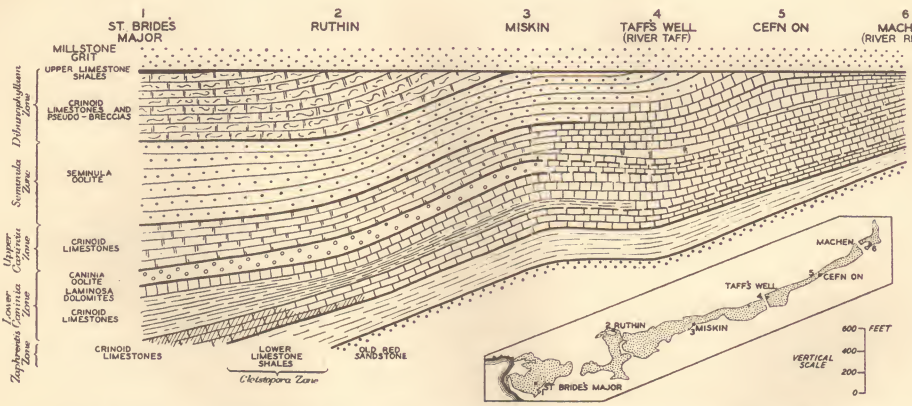


FIG. 17.—*Lateral Changes in Lithology and Thickness of the Carboniferous Limestone of the South Crop of the South Wales Coalfield.*
(In part after Dixey and Sibly.)

with occasional calcitic beds that form a thick lagoon phase. Near Risca the zone disappears beneath the unconformably transgressive Millstone Grit, but where it reappears on the North Crop between Llangattwg and the Vale of Neath the total maximum thickness is only about 60 ft.; it consists of muddy and porcellanous limestones, with some bands of clay, oolite, and quartz conglomerate—deposits mostly of lagoon-phase type—in which the chief fossils are calcareous algae.

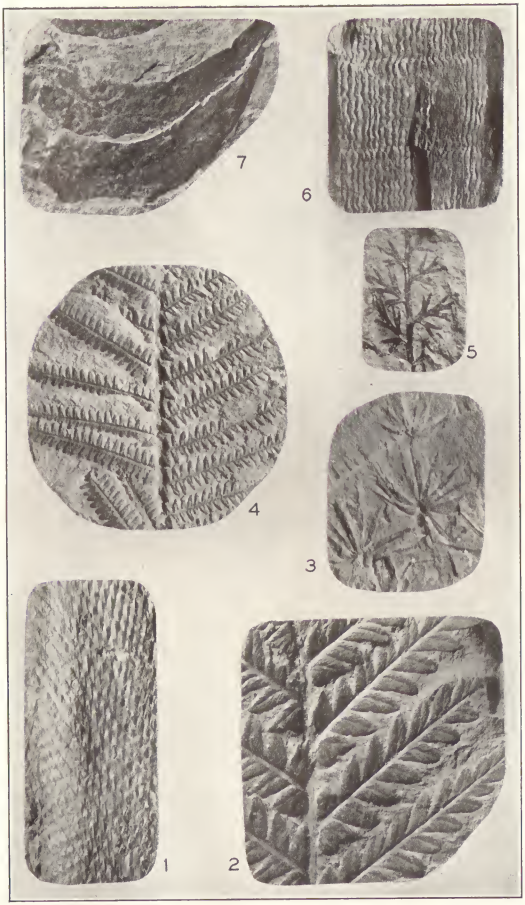
Main Seminula Zone.—Usually sharply separated lithologically from the crinoidal limestones and pseudobrecciated beds of the Dibunophyllum Zone, the Seminula Zone is largely composed of a massive coarse oolite, the Seminula Oolite. In the upper strata are intercalated pisolites, algal limestones, and calcite mudstones. Many of the beds are markedly false-bedded. The general characters of the zone strongly suggest deposition in very shallow water, and Dixon has inferred that at least the upper strata were laid down under lagoonal conditions. Nevertheless, the zone is one of the most uniform in lithological characters, and was possibly the most widespread of all the Avonian zones.

Fossils, though common, are not evenly distributed through the rocks but are concentrated in bands. Chief are the brachiopods *Composita* [*Seminula*] *ficoidea* and *Productus* (*Linoproductus*) *corrugato-hemisphericus* (Fig. 15), which are particularly abundant in the upper part of the zone. Corals are represented by species of *Lithostrotion* (*L. martini* and *L. basaltiforme*) and of *Carcinophyllum*. A characteristic form in the exposures of the North Crop is the brachiopod *Davidsonina* [*Cyrtina*] *carbonaria*, which ranges to the top of the zone. It is rare in the southern outcrops.

In Gower and the Vale of Glamorgan the zone is about 1,000 ft. thick. Along the North Crop, however, although most of it seems to be present, its thickness does not exceed 400 ft. This attenuation is not accompanied by any marked lithological or faunal changes, except that sandy beds appear both at the base (where they may be conglomeratic with large quartz pebbles) and in the upper beds beneath the Dibunophyllum Zone.

Dibunophyllum Zone.—The beds of this zone characteristically consist of fairly deep-water crinoid, coral, and brachiopod limestones with some oolites. Rarely, contemporary shallowing is indicated by the occurrence of thin carbonaceous bands. Many of the beds are pseudobreccias—rocks that Dixon has described as being the product of recrystallization of muddy limestones, the calcite segregating into pure ' fragments ' set in a proportionately muddier ' matrix '; on weathering, the ' matrix ', being soft, is easily eroded, while the ' fragments ' stand out as irregular projections of the bedding planes, giving the rock the appearance of a true breccia. The contrast between ' fragments ' and ' matrix ' is not infrequently enhanced by the selective dolomitization of the latter. The topmost beds of the zone (Upper Dibunophyllum Subzone—D_3) are represented by the argillaceous phase of the Upper Limestone Shales (the ' Black Lias ' of Gower) ; in places, as at Bishopston in Gower and along the North Crop, the muddy limestones are frequently weathered, by the leaching out of the calcium carbonate, and form rottenstones that have been worked for polishing powder.

Fossils include an abundance of clisiophyllid corals (*Dibunophyllum, Lonsdaleia, Aulophyllum*) together with species of *Lithostrotion* and *Palaeosmilia*. Many kinds of brachiopods are also represented, the most common being species of *Productus*. The conditions of deposition of the Upper Limestone Shales appear



TYPICAL FOSSIL PLANTS OF THE COAL MEASURES.

1. Part of the stem of a club moss. $\times \frac{1}{2}$. *Lepidodendron sp.* **2.** Part of the frond of a seed-fern. $\times 1$. *Mariopteris nervosa* (Brongniart). **3.** Leaves of a horsetail. $\times 1$. *Annularia radiata* (Brongniart). **4.** Part of the frond of a tree-fern. $\times 1$. *Asterotheca miltoni* (Artis). **5.** Part of the leaf of a fern-like plant. $\times 2$. *Sphenopteris* cf. *sancti-felicis* (Stur). **6.** Pith-cast of the stem of a horsetail. $\times 1$. *Calamites undulatus* (Sternberg). **7.** Part of the frond of a seed-fern. $\times 1$. *Neuropteris scheuchzeri* (Hoffmann).

(*A*.1086)

A.—RAISED BEACH, NEAR BRANDY COVE, GOWER.

(For description of plate, *see* p. vi.)

(*A*.389)

B.—GORGE OF THE RIVER RHEIDOL.

to have been inimical to most of the corals of the underlying ' standard ' limestones, and the phase is characterized by the common occurrence of zaphrentids (*Zaphrentis enniskilleni, Z. oystermouthensis, Caninia sp.*) with productid and spiriferid brachiopods, e.g. *Productus* (*Eomarginifera*) *longispinus, P. concinnus, Spirifer oystermouthensis, Martinia multicostata, Spiriferina sp.* In the southern outcrops the upper part of the limestone phase (Middle Dibunophyllum Subzone—D_2) is not readily separated from the lower beds (Lower Dibunophyllum Subzone—D_1), but on the North Crop it contains *Lonsdaleia floriformis, L. duplicata, Palaeosmilia regia, Orionastrea ensifer*, and the species of *Lithostrotion* with small corallites (*Lithostrotion junceum, L. m'coyanum*, and *L. portlocki*) which are absent from the beds beneath. *Palaeosmilia murchisoni, Productus* (*Linoproductus*) *hemisphaericus*, and giganteid species of *Productus* are common forms of the Lower Dibunophyllum Subzone.

The whole zone reaches a thickness of about 800 ft. in Gower, at least 800 ft. in the southernmost outcrops in Pembrokeshire, and more than 600 ft. in the Bridgend district of the Vale of Glamorgan (where it is not all exposed). In southern Pembrokeshire and along parts of the main North Crop (especially east of the Vale of Neath) the zone is progressively overstepped by the Millstone Grit, but between Llandebie and the Tawe Valley, and again at Kidwelly and Pendine, all three divisions can be recognized. They show, however, great attenuation, reaching a maximum thickness of less than 300 ft. and a thickness at Kidwelly and Penwyllt of less than 200 ft.

This thinning of the zone is accompanied by considerable lithological changes. In the northern outcrops the Lower Dibunophyllum Subzone consists for the most part of a massive false-bedded oolite, the Light Oolite, resting on a calcareous sandstone, the Honeycombed Sandstone, that becomes decalcified on weathering and then possesses a cellular structure.

Crinoidal limestones and pseudobreccias are found only in the western exposures between Kidwelly and Llandebie. Corals are rare in the Light Oolite, the most abundant fossil being *Productus* (*Linoproductus*) *hemisphaericus*, which occurs in profusion.

In the eastern outcrops between the Tawe and Neath valleys seams of sand appear in the Light Oolite, and the texture of the rock may approach that of a grit. The Middle Dibunophyllum Subzone is even more arenaceous, few of the limestone beds near Penwyllt and Penderyn being free from sand ; it also contains much nodular and tabular chert. Considerable faunal changes accompany this development of a sandy facies, and were in part probably occasioned by the changing conditions of sedimentation. In the southern outcrops of South Pembrokeshire, Gower, and the Vale of Glamorgan, the Middle Dibunophyllum Subzone, though containing a rich fauna of corals, is not readily distinguished from the Lower either on lithological or on faunal grounds, for such diagnostic forms as *Lonsdaleia, Orionastrea, Palaeosmilia regia*, and *Productus productus* are rare or absent. At Kidwelly the zone presents the same crinoidal and pseudobrecciated facies, free of sand, as that of Gower a few miles to the south ; at the same time it possesses a richer fauna than the equivalent beds in Gower, and the usual species of *Dibunophyllum* and *Productus* are accompanied by the diagnostic forms listed above. North-east of Kidwelly the subzone is cut out for a short distance by the Millstone Grit transgression, but it reappears at Crwbin, some 4 miles away, totally different in thickness, lithology, and fossils. The 80 ft. of ' standard ' limestones near Kidwelly are replaced by over 200 ft. of lime-

stones with sandy and conglomeratic layers, coarse brecciated beds, and calcite mudstones ; the abundant corals and brachiopods of the western outcrop are, with the exception of the species of *Productus*, almost wholly absent, but their place is taken by a profusion of molluscs (gastropods and lamellibranchs), particularly *Sanguinolites contortus* and species of *Aviculopecten*. Farther east, towards Penwyllt, the lithology remains siliceous, but the contained fauna becomes richer and in the easternmost outcrops is remarkably similar to that near Kidwelly, containing clisiophyllid corals together with many zaphrentids (*Zaphrentis enniskilleni, Caninia juddi*).

Conditions of Deposition.—The details of succession, as given above, may be summarized in the statement that the major marine cycle of sedimentation preserved in the Avonian rocks is composed of three minor bathymetric cycles. The first begins with the shallow-water muddy and sandy strata of the Lower Limestone Shales ; its deep-water phase is expressed in the crinoid and coral limestones of the Zaphrentis and the Lower Caninia Zones ; its close is marked by the false-bedded Caninia Oolite. The second, beginning with the lagoon deposits of the basal Upper Avonian, is chiefly displayed in the fossiliferous zaphrentid-phase deposits of the Upper Caninia Zone, which are followed by the shallow-water oolites and pisolites of the Seminula Zone. The crinoidal limestones and pseudobreccias of the Dibunophyllum Zone, closing with the Upper Limestone Shales, mark the third.

Lateral variation in thickness is consistently one of attenuation towards the north in Pembrokeshire and towards the north and north-east in Glamorganshire and Monmouthshire. This thinning is almost invariably accompanied by lithological changes. In the Upper Avonian, the pure limestones of the south are replaced by sandy and even conglomeratic beds on the north, the Honeycombed Sandstone of the Lower Dibunophyllum Subzone being an example. In the Lower Avonian and in the Upper Caninia Zone, the principal development in the northern and eastern outcrops is that of penecontemporaneous dolomite associated with mudstones indicative of lagoon conditions. It thus becomes evident that the deeper waters in which occurred maximum sedimentation lay towards the south, and the contemporary shore-line, sometimes with wide lagoonal flats, sometimes with streams bringing in much terrigenous sand and mud, lay not far to the north of the present outcrops.

The Intra-Avonian Unconformity.—In the southern outcrops of the Carboniferous Limestone, the Upper Avonian rests on the Caninia Oolite with a marked change in lithology, but without other indication of a break in the succession. But in eastern Gower, and, to a still greater degree, at West Williamston on the Carew Anticline, there is evidence that the Oolite was slightly eroded, pitted, and piped before the overlying beds were laid down. It is clear, therefore, that the uplift that closed the minor cycle of deposition of the Lower Avonian with the Caninia Oolite culminated at these places in elevation sufficient to bring that bed at least within reach of tidal or current scour, if not to lift it completely above sea-level. Still farther north, nearer the contemporary shore-line and the land-mass of St. George's Land, the regression of the sea marked by this elevation was so great that not only was there a halt in deposition but the rocks already formed suffered extensive erosion and removal. The Upper Avonian then rests with more or less considerable unconformity on the Lower, the successive beds of the Upper Avonian overlapping northwards and overstepping progressively older beds of the Lower in the process (Fig. 16).

The complete geological history cannot be precisely determined, because much of the evidence is now hidden beneath the Upper Carboniferous rocks of the Coalfield, but sufficient is displayed between Abergavenny and the Tawe Valley to demonstrate the main events. In that neighbourhood the full succession of zones (though much attenuated) is represented in the outcrops as far west as the Vale of Neath ; there, however, the Upper Caninia Zone thins and disappears, while the Caninia Oolite is reduced to a thickness of only 5 or 6 ft. At that point, therefore, a slight unconformity exists between the Seminula Zone and the Oolite, the Upper Caninia Zone being absent through overlap. Between the valleys of the Neath and the Tawe the thin remnant of the Caninia Oolite is first overstepped and then the dolomites disappear to the base of the Zaphrentis Zone, so that the Seminula Zone rests directly upon the Lower Limestone Shales at Penwyllt. From that place westwards the present strike runs in a direction approximately parallel with the bathymetric lines of Avonian times, for along the whole outcrop to Kidwelly the Upper and Lower Avonian present this unconformable relationship. At no point does the Seminula Zone transgress the Lower Limestone Shales to rest on older rocks, though there are considerable variations in the thickness of the Shales which may be reduced to a minimum of 15 ft.

In Pembrokeshire the North Crop shows a similar development. At West Williamston the Caninia Oolite is eroded and slightly transgressed by the succeeding Upper Caninia Zone, and this transgression increases rapidly northwards so that on the north flank of the Pembrokeshire Coalfield the whole of the Lower Caninia Zone is absent. At Pendine the Seminula Zone rests on about 70 ft. of the Zaphrentis Zone, but farther west only the Lower Limestone Shales remain of the Lower Avonian. These are followed in places (as near Blaencilcoed and Castle Ely) by high strata of the Upper Caninia Zone, which seem to have been deposited in pockets on the eroded surface of the older rocks ; but usually the deposition of the Upper Avonian did not begin until Seminula times. The maximum overstep is displayed near Haverfordwest, where the Lower Limestone Shales and the Old Red Sandstone are transgressed by the Seminula Zone, which there rests on Silurian rocks. Presumably also (though the evidence has long been removed by erosion) at one time the Upper Avonian along the whole of the North Crop overstepped the Lower, to be banked against the rising shores of Old Red Sandstone or Lower Palaeozoic rocks of St. George's Land.

The Post-Avonian Unconformity.—After the deposition of the Carboniferous Limestone there was again considerable elevation of the Avonian cuvette, accompanied by marked changes of geography ; the succeeding beds, the Millstone Grit, thus not only differ greatly in lithology from the underlying limestones but in places, particularly along the northern and north-eastern crops (where elevation was at a maximum), rest on an eroded surface from which more or less considerable thicknesses of sediment were removed. Details of the unconformity are given later (see p. 64), and it is sufficient to mention here that its magnitude is measured by the complete absence of the Carboniferous Limestone at some localities, the Millstone Grit then resting directly on Old Red Sandstone or on older rocks.

Variations in the limestone succession may then be summarized as follows. Changes in thickness or lithology (without removal of beds) are attributed to the proximity of a shore-line lying to the north. An extensive regression of the

Avonian sea from this shore-line at the close of Lower Avonian times caused the erosion of many or all of the beds already formed, and delayed the deposition of younger rocks until a more or less late date in Upper Avonian times : that is, along the North Crop the absence of some of the Lower Avonian zones is attributable to erosion after deposition, while the absence of some of the Upper Avonian zones is due to their never having been deposited. Many or all of the Avonian zones may be absent as a result of erosion before the deposition of the Millstone Grit ; as with the mid-Avonian unconformity, this break is most marked along the North Crop near the contemporary shore-line.

MILLSTONE GRIT

Lithology and Succession.—The strata succeeding the Carboniferous Limestone are sharply distinguished lithologically from the underlying clear-water typically marine shelly and coralliferous limestones, and consist of a variable group of sandstones and shales. Many of the beds show rapid lateral changes from fine silty muds to coarse sandstones and grits and even to conglomerates. Most of the coarser rocks are wedge-bedded and current-bedded, and few horizons, except in a broad lithological sense, can be traced over the whole of South Wales. The essential nature of the sediments thus strongly suggests conditions of accumulation characteristic of the estuaries of large rivers, where fast currents loaded with terrigenous material deposit their burden in lenticles and festoons ; any one bed of such a series has no great areal extent, but as a whole the series of deposits may present the same broad appearance over many square miles.

The coarser rocks are quartzites and quartz conglomerates and contain grains and pebbles often cemented in a siliceous matrix. In general appearance, apart from the absence of red colour, they closely resemble some of the grits and conglomerates of the upper beds of the Old Red Sandstone, and, like much of the latter formation, a considerable proportion of the Millstone Grit appears to have been derived from a land-mass of Pre-Cambrian (and probably Lower Palaeozoic) rocks lying to the north. The quartzitic rocks, of which the Basal Grit is the chief, form hard bands strongly resistant to denudation and give rise to escarpments surrounding the Coalfield. In the Carmarthenshire Fans, where the coarse upper beds of the Old Red Sandstone become attenuated westwards, the Basal Grit takes their place and forms the topmost protective element of the escarpment edge ; even in the Abergavenny district, where the Quartz Conglomerates of the Upper Old Red Sandstone are well developed, the Millstone Grit quartzites and grits mark the scarp summit.

In detail the succession within the Millstone Grit at any one locality often shows rhythms of sedimentation, possibly associated with oscillations of the floor of deposition or with seasonal and climatic changes. Beginning with a coal seam (rarely of any economic importance and generally little more than a black carbonaceous band) the complete cycle shows progressive changes through grey or black fine-grained shale and sandy shale into a quartz-silt or fine-grained grit that merges upwards into a quartz conglomerate ; this coarse bed may show evidences of being an old soil, and is overlain by another coal streak beginning the succeeding cycle. A comparable broad cycle characterizes the Millstone Grit as a whole, and has enabled a classification of the formation into the following lithological divisions (Fig. 19):—

3. Farewell Rock, so called because, once reached in mines, it indicates little likelihood of workable coal being found beneath. It consists of brown, green, and yellow sandstones and quartzites.
2. Middle Shales. Dark grey, blue, and black shales with bands of grit, sandstone and quartzite. The Twelve-Foot Sandstone near the base is a well-marked horizon.
1. Basal Grit, consisting of a very variable group of quartz-grits, quartzites, sandstones, and conglomerates, some of the beds being very pure and being worked for fire-brick ('silica brick'). Bands of shale, thin and insignificant in the lower part, become increasingly abundant upwards, so that the division passes by stratal alternation into the overlying Middle Shales.

As has been suggested, the sediments were derived from the north and carried southwards, where they were deposited in an estuary or a number of estuaries. The contemporary land-masses and the shore-line or coastal shelf, as in Avonian times, lay not far to the north of the present outcrops, and deep waters extended over the Bristol Channel on to Cornwall and Devon. As a whole, then, the Millstone Grit shows increasing fineness of grain when traced southwards away from the shore-line, in which direction the thick arenaceous beds of the North Crop become attenuated and finally disappear, so that in southern Pembrokeshire, in Gower, and in the Bridgend district the formation consists of a monotonous and not readily divisible succession of shales with thin impersistent sandstones, quartzites, and grits.

Fossils.—With the great change in conditions of deposition from limestones to grit and shales, there was a rapid extinction or migration of the abundant corals and brachiopods characteristic of the Avonian strata, and these forms, except in occasional impure calcareous bands, are practically absent from the Millstone Grit. Their place is taken by animals adapted to life in a muddy environment, chiefly by lamellibranchs and goniatites (Fig. 18). Even these are found only at certain horizons in the shales, the arenaceous beds being almost wholly unfossiliferous, though impressions of drifted plants, such as *Lepidodendron*, *Sigillaria*, and *Stigmaria*, may occur even in the coarsest conglomerates.

The invertebrate fauna, including the lamellibranchs *Dunbarella*, *Posidonia*, *Aviculopecten*, *Nuculana*, and *Sanguinolites*, is chiefly of shallow-water marine type and contains occasional brachiopods (*Chonetes*, *Productus*, *Spirifer*, and the relatively common mud-burrowing *Lingula*) and rare corals (*Zaphrentis*). But some bands, particularly in the upper part of the Grit where they are associated with thin coal seams, contain freshwater and brackish-water lamellibranchs (*Carbonicola* and *Anthraconaia*) that link the formation with the overlying Coal Measures, and mark the approach of more typically lagoon and swamp conditions.

The goniatites are particularly important. By their aid it has been possible to apply Bisat's zonal scheme to the Millstone Grit of South Wales, and Evans and Jones, Dix, and especially Ware, have shown that at some localities at least the major divisions are present. The following are recognized :—

4. Gastrioceras Zone (G). *Dunbarella* [*Pterinopecten*] *elegans* appears to be characteristic of this zone, which also contains occasional *Reticuloceras* and *Homoceras* in association with *Gastrioceras*.
3. Reticuloceras Zone (R). Besides many kinds of *Reticuloceras*, this zone also contains some *Homoceras*, but *Gastrioceras* is absent. *Dunbarella speciosa* and *Posidoniella rugata* are characteristic lamellibranchs.
2. Homoceras Zone (H).
1. Eumorphoceras Zone (E). This zone is imperfectly known in South Wales, and so far except occasionally in the upper beds has yielded only poorly preserved goniatites.

The Gastrioceras Zone includes the upper part of the Millstone Grit and the lower part of the Coal Measures; and despite the change of lithology it may well be that the Farewell Rock, and possibly some of the Middle Shales, should on faunal grounds more properly be included in the Coal Measures than in the Millstone Grit. Moreover, Ware has shown that the upper part of the Millstone Grit falls into the lamellibranch zone of *Anthraconaia lenisulcata*, which in other areas includes the lower beds of the Coal Measures. According to Dix, the plant zones, although based on specimens from relatively few horizons, likewise overlap the lithological division between the Farewell Rock and the Lower Coal Series: the base of the (partly Coal Measures) Zone of *Neuropteris schlehani* and

FIG. 18.—*Millstone Grit and Coal Measures Goniatites.*

(All natural size except where stated.)

A, *Eumorphoceras bisulcatum* Girty, Zone E, Millstone Grit; **B**, *Homoceras beyrichianum* (Haug), two views, Zone H, Millstone Grit; **C**, *Reticuloceras reticulatum* (Phill.), mut. *superbilingue* Bisat [=mut. γ Bisat], Zone R, Millstone Grit, *Diagrammatic reconstruction*; **D**, *Gastrioceras cancellatum* Bisat, Zone G, Millstone Grit, *Diagrammatic reconstruction*; **E**, *Homoceratoides jacksoni* Bisat, Marine band in Similis-Pulchra Zone, Coal Measures.

Lyginopteris hoeninghausi (Fig. 21) may coincide with the base of the Gastrioceras Zone; it is underlain by the Zone of *Pecopteris aspera*, falling wholly within the Reticuloceras Zone, and the Zone of *Lyginopteris strangeri* and *Alethopteris* cf. *parva* which lies partly within the Reticuloceras Zone but may extend downwards to include the whole of the Homoceras Zone.

Lateral Variation.—In the discussion of the Avonian succession it was noticed that in places there is a considerable stratigraphical break between the Millstone Grit and the Carboniferous Limestone. It follows that there was earth-movement before the deposition of the Grit, which thus rests with more or less great unconformity upon an eroded and planed surface of the post-Avonian folds; occasionally, as at Penlan near Kidwelly and at Haverfordwest, it

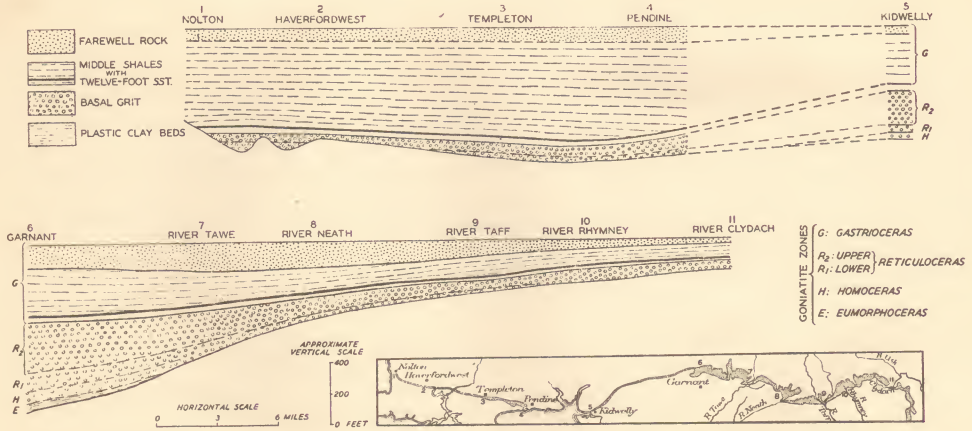


FIG. 19.—*Sections showing Lateral Changes in the Millstone Grit of the North Crop of the South Wales Coalfield.*
The precise boundaries of the zones are not known with certainty in Pembrokeshire.
(In part after Ware, Evans and Jones.)

completely oversteps the Limestone and rests on Old Red Sandstone or older rocks.

The boundaries of the Avonian zones, outcropping on this planed surface and then behaving as approximate contour-lines, give a measure of this puckering. They are shown in Fig. 20. From this illustration it is clear that on the whole, particularly in the central and western parts of the province, the greatest amount of erosion occurred along what is now the North Crop—that is (as would be expected) in the neighbourhood of the contemporary shore-line. In the deeper water farther south elevation was insufficient to lead to such extensive removal of Avonian strata. The general east-and-west trend is, however, broken by two marked diversions of the natural contour-lines. One of these occurs at Penlan, where a relatively sharp anticline in the Carboniferous Limestone was eroded to expose a core of Old Red Sandstone upon which the Millstone Grit (the Penlan Quartzite—an outlier of the Basal Grit) was deposited. The other is a larger and broader structure of which only part is seen along the eastern flanks of the Coalfield, where the sub-Millstone Grit Avonian outcrops swing south towards the Vale of Glamorgan. This upfold, from which, in the Abergavenny district, all the Avonian strata, except the Lower Limestone Shales, were removed before the deposition of the Millstone Grit, lies between the Carboniferous Limestone of South Wales and that of the Forest of Dean (where the whole of the Lower and part of the Upper Avonian is preserved). It thus appears that this upfold approximately coincides with the Usk–Cardiff Anticline, a structure which, though largely of post-Carboniferous age, must therefore have been in process of formation during early Carboniferous times. Between the Penlan and the embryonic Usk upfolds was an area, an embayment of gently synclinal structure, in which the upper zones of the Carboniferous Limestone were preserved, particularly between Kidwelly and the Vale of Neath.

These contemporary folds had a direct effect on the Millstone Grit succession and were probably actually in process of formation throughout the deposition of the Grit. In particular, the eastern development around the crop from Merthyr Tydfil through Pontypool to the Ebbw Valley at Risca reaches a thickness of only 200 to 300 ft. as contrasted with 1,000 ft. farther west near Llandebie and Cross Hands, and with nearly 2,000 ft. in Gower. This extreme attenuation is due in part to the effects of banking against the rising anticlinal ridge, so that the individual zones are very thin ; it is also to be attributed to the fact that submergence of the ridge (or the flanks of the ridge) did not occur until much of Millstone Grit times had elapsed, for the lowest zone present is the Reticuloceras Zone, the Eumorphoceras and Homoceras Zones never having been deposited (Fig. 19) ; in places also, as near Risca, the Basal Grit is overlapped by the Middle Shales. A similar succession, though much thicker and not quite so incomplete, occurs near Kidwelly, where the effect of the Penlan axis is shown by the Homoceras Zone forming the local base of the Grit, the Eumorphoceras Zone being absent.

In the synclinal embayment between the Penlan and Usk ridges, the succession is not only thicker, but all the zones have been shown to be present, and in the neighbourhood of Llandebie and Cross Hands there was almost complete continuity of deposition from Lower into Upper Carboniferous strata. Accordingly the lithological changes are transitional and not abrupt, the argillaceous and silty Upper Limestone Shales being overlain by fine mealy sands with chert

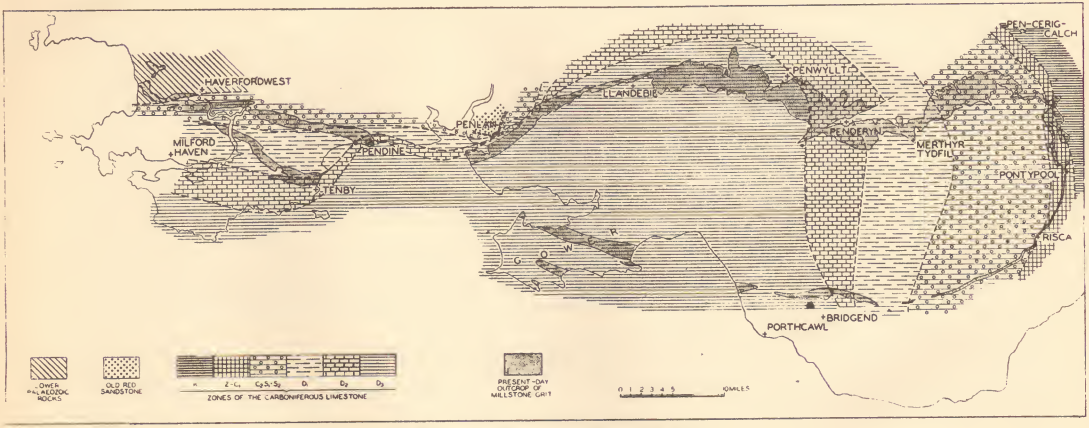


FIG. 20.—*Map of the sub-Millstone Grit Floor.*

The boundaries of the Avonian Zones are only approximate: in particular, it is difficult to recognize precisely the effects of the post-Carboniferous (Armorican) movements, so that the Vale of Neath disturbance is shown as affecting the outcrop of the Dibunophyllum Zone, whereas in fact it did not come into being until after the deposition of the Millstone Grit.

cores (the Plastic Clay Beds) that are followed upwards by the sandstones and quartzites of the Basal Grit. In this region the lowest chert beds are frequently banded and contain Radiolaria.

The Millstone Grit in the southern outcrops of Gower and the Vale of Glamorgan consists of a series of shales with thin sandstones, 1,500 to 2,000 ft. thick, containing all four goniatite zones. Banded radiolarian cherts similar to those of the North Crop occur at or near the base, where they are associated with the green phosphatic mineral wavellite ; Dixon has suggested that they accumulated in still waters under lagoonal conditions.

The development of the Millstone Grit in Pembrokeshire conforms with that of the ground farther east. In the southern outcrops of the Tenby district the precise relations with the Carboniferous Limestone are difficult to determine owing to disturbance along the line of the Ritec Fault. At least 1,000 ft. of strata, chiefly shales with quartzitic sandstones, are present and include the Homoceras, Reticuloceras, and Gastrioceras Zones ; the Eumorphoceras Zone has not yet there been recognized, but it is almost certainly represented in the radiolarian cherts of the more southerly outcrops around Bosherston. In the northern outcrops near Pendine the formation is thinner and becomes increasingly attenuated towards and beyond Haverfordwest, the Basal Grit ultimately being completely overlapped by the Middle Shales near Nolton (Fig. 19). In the Haverfordwest district the lowest beds present belong to the Reticuloceras Zone, and rest with great unconformity on the Seminula Zone of the Avonian or on Lower Palaeozoic rocks. It is clear, therefore, that the contemporary shoreline lay in the vicinity of the present outcrops.

Despite the variation in the succession along the North Crop, and its incomplete nature in the neighbourhood of anticlinal uplifts and of the shore-line, the three lithological divisions are nearly everywhere recognizable, though there is little doubt that the upper boundary of the Basal Grit and the lower boundary of the Farewell Rock transgress the time planes as marked by the goniatites.

COAL MEASURES

Lithology and Succession.—The strata of the Coal Measures consist almost entirely of terrigenous material derived from nearby sources and carried into a trough by rivers from a land-mass lying, as in Avonian and Millstone Grit times, to the north. On the whole the deposits appear to have been laid down under estuarine or freshwater conditions ; marine beds are of rare occurrence and are restricted to the lower part of the sequence. At no time during the accumulation of the Coal Measures does the area appear to have been at any great height above sea-level, and while the coal seams were being formed it was a shallow swamp or marsh covered by luxuriant vegetation through which tributaries and distributaries of large rivers meandered.

In detail, the sedimentation of the Coal Measures, like that of the Millstone Grit, was in a succession of rhythmic cycles, probably resulting from slight oscillations. After the formation of each coal seam on a foundation sufficiently near water-level to allow the growth of a dense vegetation, there was sharp subsidence so that the succeeding beds consist of fine-grained shale, sometimes even of impure limestone, of relatively deep-water marine or estuarine origin. These are followed by shales with a freshwater fauna of mussels, which in turn

gradually pass upwards into sandy shales, sandstones, and sometimes grits and conglomerates. As the amount of coarse terrigenous material increased the inflowing currents became retarded and less powerful, so that the coarse sands are followed by shallow and freshwater sandy muds. Vegetation, incapable of growth in deep water or in fast-flowing currents, was enabled to grow outwards on to the mud which then became a seat-earth (ultimately a fireclay deficient in alkalis) for the overlying coal seam formed from the accumulation of the decaying plants. Usually the cycle is not completely represented, one or more elements being omitted ; nor is there perfect regularity in the proportionate thickness of the elements. Complementing the major rhythmic cycle of grit-shale-sandstone of the Millstone Grit, there is also a broad major cycle of shale-sandstone-shale in the Coal Measures, and on this lithological basis (Fig. 21) the Measures have been divided into :—

3. Upper Coal Series or Supra-Pennant Series. Predominantly shales with some sandstones.
2. Pennant Series. Predominantly sandstones.
1. Lower Coal Series. Predominantly shales.

Lower Coal Series.—The shales of this division crop out at the foot of the Pennant escarpment, and, being relatively soft and easily eroded, they form strike depressions ; they also crop out in the core of the Maesteg Anticline, and appear in narrow inliers in the floors of some of the deeply entrenched valleys of the Rhondda (Figs. 22 and 23). They consist for the most part of a monotonous series of grey, blue, and pyritous black shales often imperfectly laminated and containing fine flakes of mica. Some of the beds are highly carbonaceous and pass into a cannel shale or a cannel coal. Usually there is only a minor development of sandstones. Over much of the Coalfield Cockshot Rock, a hard siliceous sandstone or grit, forms characteristic beds between the Red and Stwrin coals or their equivalents. Locally, other sandstones of considerable thickness may occur, but they are usually impersistent. A feature of the Series, particularly of the lower part, is the abundance of iron ore occurring as a penecontemporaneous segregation (often around a vegetable core) of argillaceous chalybite (clay ironstone) in the form of nodules or in definite bands ('pins') arranged parallel with the stratification. At one time this ore formed the principal source for iron used in the South Wales metal industries, but none is now worked. There is an increase in quantity, but a decrease in quality, of the ore as the ironstone bands are followed westwards and south-westwards. The Series contains the greatest number, the thickest, and the most important coal seams in South Wales.

At a maximum the thickness of the Lower Coal Series reaches some 3,000 ft. in the Swansea district, but it becomes thinner as the group is traced towards the north-east and east. In the Maesteg district it is about 2,100 ft. ; near Merthyr Tydfil and in the south-east near Cardiff, 1,400 ft. ; while in the Pontypool district and the outcrops about Abertillery it reaches a minimum of slightly less than 800 ft. The maximum proportionate south-westward increase in thickness takes place in the measures above the horizon of the Lower Pinchin Seam, the Llynfi Rock near Swansea being about 1,200 ft. thick.

Pennant Series.—Over most of the Coalfield there is a clear line of division, both lithological and topographical, between the soft shales of the Lower Coal Series and the massive scarped sandstones of the Pennant Series, the actual junction being marked by the No. 2 Rhondda (of Rhondda) or Lower Pinchin coal (Pl. IIB).

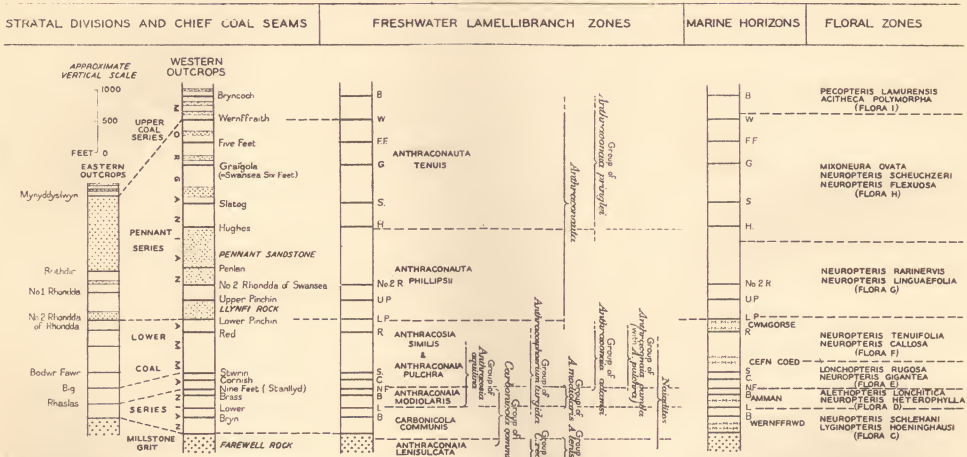


FIG. 21.—*Vertical Sections showing the Stratal and Zonal Sequence of the Coal Measures.*

Typically, the rocks of the Pennant Series are thick massive feldspathic and micaceous sandstones and grits (the Pennant Sandstone) much used for building ; when unweathered they are blue-grey, but they rapidly become rusty-brown on exposure. Many bands are highly false-bedded and indicate conditions of deposition in proximity to a land-mass rapidly eroded by fast and powerful streams. A number of minerals common to the two formations suggest that much of the Pennant may have been derived by erosion of the Old Red Sandstone, though Heard has suggested a source of origin to the south-west. Some of the beds are coarse-grained and may be conglomeratic ; not infrequently derived pebbles of coal and ironstone incorporated in the sandstones prove the contemporaneous erosion of already formed measures (probably of the Lower Coal Series). In the eastern outcrops shales are subordinate and no important workable coal seams occur. Traced westwards, however, the massive Pennant sandstones tend to be confined to the lower part of the series (below the Hughes Vein) and the upper part becomes more argillaceous, so that in the Swansea district shales and sandy shales are the chief rock types. At the same time there is an increase in the number and quality of the coal seams present and, with the Hughes Vein, several higher seams have been extensively worked between the valleys of the Neath and the Gwendraeth.

In the south and west of the Coalfield a prominent sandstone, the Llynfi Rock, reaching a thickness of over 1,000 ft., occurs above the Lower Pinchin seam, and is separated from the lithologically similar Pennant Sandstone only by a thin group of shales. In the eastern and north-eastern outcrops, however, it forms only an insignificant feature.

Towards the base of the Pennant Series, especially in the eastern outcrops, there are a number of beds of red clay and mudstone. These, described by Cox and Howell as the Deri Beds, appear to have accumulated in stagnant waters, possibly under conditions of some aridity of climate. In appearance they resemble the red Etruria Marls of Staffordshire and the Ruabon Marls of North Wales.

The Pennant Series has a maximum thickness of over 4,000 ft. in the Swansea district, but, like the Lower Coal Series, it thins rapidly towards the east and north-east and is some 1,600 ft. near Pontypridd, about 1,000 ft. near Merthyr Tydfil and Newport, reaching a minimum of little more than 600 ft. around Pontypool and Abertillery.

Upper Coal Series.—The strata of this series are exposed only as small downfolded and isolated outliers occupying the cores of the Gelligaer and Llantwit–Caerphilly synclines on the east and the Gowerton and Llanelly synclines on the west ; a small outlier is also let down in the Dyffryn Trough (Figs. 22 and 23). In the central tracts of the Coalfield the axial upfold of the Maesteg Anticline has resulted in these higher strata having been completely removed by erosion.

The Series consists of shales and sandy shales with subordinate soft thin sandstone bands, the whole giving rise to rather featureless country. Lithologically, it is readily separable in the eastern outcrops from the underlying Pennant Sandstone, the Mynyddislwyn Seam occurring at the junction. Near Swansea and Llanelly the passage from the argillaceous upper beds of the Pennant Series is much more gradual, though the Mynyddislwyn horizon can be recognized in the Wernffraith or Swansea Four Feet Seam. Thin coals, including the Llantwit and Grovesend seams, are unimportant. Clay ironstones

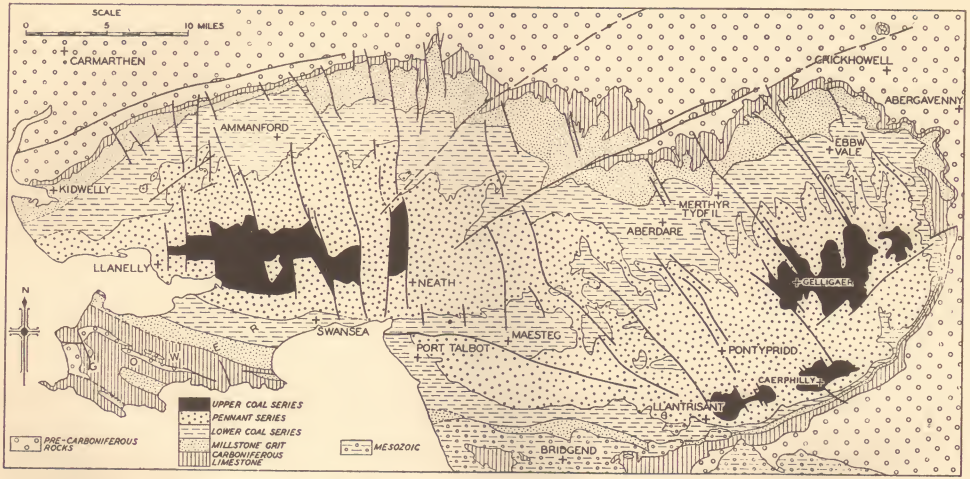


FIG. 22.—*Map of the South Wales Coalfield.*

also occur. On lithological grounds the series in the eastern outcrops has been divided into two groups. The lower, the Llantwit Measures, is of normal type and contains workable coal seams. The upper, the Supra-Llantwit Measures,

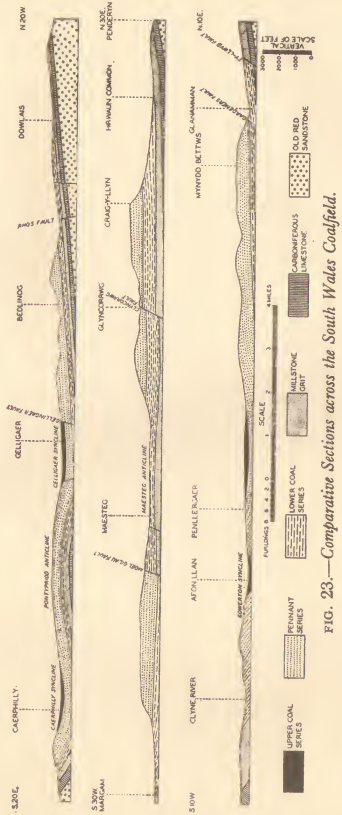


FIG. 23.—*Comparative Sections across the South Wales Coalfield.*

consists of red sandstones and marls and purple shales devoid of coal seams ; these beds presumably indicate the onset of the arid climate that marked the close of the Coal Measures and have been compared with the Keele Beds of the English Midlands ; similar red and purple beds occur above the Grovesend coals in the Gowerton Syncline.

Owing to post-Carboniferous erosion the complete original thickness of the Upper Coal Series is not preserved in South Wales, and measurements of existing strata are inconclusive. The red beds occurring in the highest measures give some (though uncertain) indication, however, of considerable thickening towards the south-west and west. Thus in the Gowerton Syncline over 800 ft. of normal grey coal-bearing strata form the greater part of some 1,000 ft. preserved, whereas in the Gelligaer and Llantwit–Caerphilly synclines the red beds appear only about 300 ft. above the Mynyddislwyn Seam.

The Pembrokeshire Coalfield.—In the Pembrokeshire Coalfield the intense folding, crumpling, and faulting that the Coal Measures suffered during the Armorican orogeny so disturbed the stratal succession that it is difficult to recognize the three subdivisons seen in the ground farther east. The principal coal-bearing beds of the Saundersfoot district are clearly the equivalents of the lower part of the Lower Coal Series of the Gwendraeth Valley, the Timber Vein being at the same horizon as the Stanllyd, and the Lower Level Vein as the Lower. Higher beds come in along the axis of the syncline towards the west and north-west and near Nolton and Newgale not less than 6,000 ft. are preserved, of which the greater part appears to belong to the Lower Coal Series. Pennant-like sandstones (including the Rickets Head Sandstone) are well represented in the upper part of the sequence, and are the representatives of the Pennant Series, though its lower limit, the equivalent of the No. 2 Rhondda Seam, has not yet been recognized with certainty.

Contemporary Earth-movements.—It is clear that during the formation of the Coal Measures the contemporary shore-line lay broadly to the north of the present outcrops. Nevertheless the maximum thinning takes place in South Wales not directly towards the north but towards the north-east, consistently in all three divisions, from a total of about 8,000 ft. near Swansea to considerably less than 2,000 ft. around Pontypool and Abertillery; even in the Caerphilly–Risca district, on the same latitude as Swansea, the thickness is only about 3,000 ft. It follows, therefore, that there was an inflexion of the east-west shore-line in the neighbourhood of the present eastern margin of the Coalfield, and the strong presumption is that the Usk–Cardiff Anticline was undergoing slight but continuous uplift throughout this period. It will be recalled that the Carboniferous Limestone bears evidence of contemporary upfolding along this axis in a change of facies and of attenuation as the beds are traced eastwards along the south-east crop (Fig. 17), while in the same direction an unconformity is progressively developed beneath the Millstone Grit (Fig. 20). Against this axis the Millstone Grit in its turn shows great attenuation (though without change of facies), and overlap of the lower zones by the upper (Fig. 19). In the Coal Measures there is again attenuation, though proportionately not so great as in the Millstone Grit, and although the proximity of the fold is not indicated by marked changes of facies, Moore has shown that in the south-eastern outcrops the Pennant Series rests with marked unconformity on the Lower Coal Series.

Other evidence for relatively minor earth-movements is provided by thickness variations in the measures between the different coal seams. Though these are probably due in some degree to differential settling and compacting and to the lenticular form of certain beds, yet R. Davies and A. H. Cox have shown that the initiation of some of the north-and-south faults (at least as local sagging) traversing the Coalfield must have taken place during the time of formation of

the Lower Coal Series. There is evidence that the Caledonoid Neath and Tawe disturbances may also be in part of Carboniferous age. In Pembrokeshire much small-scale contortion and brecciation of the unconsolidated sediments appear to have taken place by contemporaneous slumping and sliding.

Faunal Zones.—Arising from their deposition in a varied and variable non-marine environment, the rocks of the Coal Measures display considerable lateral changes when traced for any distance, chief of which are the rapid thickening and thinning of many of the sandstone bands. A lithological subdivision of the Measures, even when supplemented by considerations of thickness, is then often only applicable locally, and may be unreliable or deceptive when applied to more distant areas. The difficulties are enhanced where folding and faulting greatly complicate the relationships of the rock outcrops and prevent the use of such continuous datum lines as coal seams. Until recently such crude and inexact methods have perforce been in use, but during the past decades A. E. Trueman and J. H. Davies, working at first in the anthracite district, have elucidated and, with others, have applied a method of stratal subdivision that is dependent not entirely on local circumstances of deposition but on the evolution of certain fossil lamellibranchs found in the Coal Measures. Their work has transformed Upper Carboniferous stratigraphy and has placed the task of correlation on a firm basis.

The swamps and brackish and freshwater lakes of the Coal Measures were eminently suitable habitats for a group of molluscs, closely similar to the present-day freshwater mussel *Anodonta*, that are found abundantly at various horizons throughout the Lower Coal Series, and less abundantly (owing to the predominantly sandy facies) in the higher measures. They have been referred to the genera *Carbonicola*, *Anthracosia*, *Anthracosphaerium*, *Anthraconaia*, *Anthraconauta*, and *Naiadites* (Fig. 24), different species of which have limited vertical ranges in the sequence (Fig. 21). The zones established by Trueman and Davies in terms of this vertical distribution are as follows :—

6. Zone of *Anthraconauta tenuis*.
5. Zone of *Anthraconauta phillipsii*.
4. Zone of *Anthraconaia pulchra* and *Carbonicola similis*.
3. Zone of *Anthraconaia modiolaris*.
2. Zone of *Carbonicola communis*.
[1. Zone of *Anthraconaia lenisulcata*.]

In South Wales the Lenisulcata Zone falls wholly within the strata referred to the Millstone Grit, but in other coalfields it includes beds placed in the Lower Coal Measures. The Communis, Modiolaris, and Similis–Pulchra Zones comprise the principal coal-bearing strata of the Lower Coal Series below the Llynfi Rock. The zones with *Anthraconauta* coincide with the arenaceous facies of the Llynfi Rock and Pennant Series, and the sandy shales of the Upper Coal Series. As Truman has insisted, it is therefore evident that the Coal Measures fall into two principal palaeontological divisions—a lower, the Ammanian, with a rich fauna of *Carbonicola*, *Anthracosia*, *Anthracosphaerium*, *Anthraconaia*, and *Naiadites*, and an upper, the Morganian, with a relatively impoverished fauna in which these genera (excepting the group of *Anthraconaia pringlei*) are rare or absent, but in which *Anthraconauta* appears commonly and is the typical member. It is highly probable that there is some relation between the zonal faunas and the physical environment (as now represented by lithology) in which they lived, the palaeontological break coinciding with the chief change from shales

to sandstones and with a decrease in number and importance of coal seams. Moreover, on a minor scale there seems to have been some restriction in the distribution of the different genera, large thick-shelled species of *Carbonicola* or *Anthracosia* being rarely associated in the same bed with the thin-shelled *Anthraconaia* and *Naiadites*, and generally being found in strata more thoroughly freshwater; in consonance with this differentiation such large specimens are more abundant in the measures of the North Crop (nearer the contemporary shore-line) than in those of the South Crop.

FIG. 24.—*Characteristic Freshwater Lamellibranch Shells from the Upper Carboniferous Rocks.*

(All figures natural size except F.)

A, *Anthraconaia lenisulcata* (Trueman); **B**, *Carbonicola martini* Trueman and Weir; **C**, *Anthraconaia modiolaris* (J. de C. Sowerby); **D**, *Anthraconaia pulchra* (Hind); **E**, *Carbonicola similis* (Brown); **F**, *Anthraconauta phillipsii* (Williamson); **G**, *Anthraconauta tenuis* Davies and Trueman.

In the Pembrokeshire Coalfield the Communis and Modiolaris Zones have been recognized in the measures associated with and below the Timber Vein in the Saundersfoot district, while farther west, near Nolton, Trueman has shown that the Phillipsii and Tenuis Zones occur in the strata including the Rickets Head Sandstone.

Other invertebrate fossils are relatively rare and are not so useful for zonal purposes. Dix and Pringle, in a comprehensive description of the Xiphosura of the South Wales Coal Measures, have shown that the broad twofold division is maintained in the distribution of *Belinurus* and *Prestwichianella*, the former being not uncommon in the strata below the Llynfi Rock, the latter being found only

in the Phillipsii and Tenuis Zones ; a third genus *Euproops*, however, has been recorded both from the lowest beds of the Lower Coal Series and from the top of the Pennant Series. Other arthropods include the crustaceans *Euestheria*, *Leaia*, and *Carbonita* that are common at certain horizons, while Bolton has described blattoid and other insects (*Archimylacris*, *Phylomylacris*, *Phyloblatta*, *Lithosialis*, *Boltoniella*) from various horizons throughout the Coal Measures.

Plants of the Coal Measures.—Plant incrustations are the commonest fossils in the shales of the Coal Measures, while petrifactions are occasionally found in the sandstones. Most of the plants belong to genera and families that have long been extinct. The principal groups are as follows (Pl. VI) : the 'horsetails' (Equisetales, e.g. *Calamites* and *Annularia*) ; the 'club-mosses' (Lycopodiales, such as *Lepidodendron* and *Sigillaria*) ; the pteridosperms (plants with leaves similar to those of true ferns but differing from ferns in bearing seeds, e.g. *Neuropteris*, *Alethopteris*, and *Mariopteris*) ; the true ferns, including *Asterotheca* ; and the gymnosperms (related to the living conifers, and represented by *Cordaites*).

From a systematic analysis of the proportions of the various types of plants found at the main plant-bearing horizons, D. Davies was enabled to describe the physiographical and ecological conditions under which the successive forests of the Coal Measures grew ; while Rowlands used the plant frequencies in correlating the coal seams of the Pennant Series in the Swansea district. During the past decades, however, work by Crookall and especially by Dix has greatly clarified the detailed plant succession. Crookall, applying Kidston's classification based on fossil plants, has defined his floral boundaries as follows: between the Pre-Yorkian and the Yorkian, the Cnapiog Vein ; between the Yorkian and the Staffordian, the Lower Pinchin Seam ; between the Staffordian and the Radstockian, the Hughes Vein. Dix, elaborating the results obtained in Continental coalfields, has recognized seven zones (Fig. 21), each of which is characterized by its own assemblage of plants ; she has conclusively proved what the faunal sequence had already demonstrated, namely, that the full Coal Measures succession is virtually completely represented in South Wales. The boundaries of the plant zones, however, are not conterminous with those of the lamellibranch zones.

Marine Horizons.—The rhythmic cycles of deposition characterizing the sequence of the Coal Measures include relatively deep-water phases, some of which indicate deposition in a marine, if muddy, environment. The sediments laid down during such phases differ slightly from the normal grey-blue shales and consist of soft lack-lustre black shales, often highly pyritous, and sometimes passing into a black impure muddy limestone. Even where no typical marine fossils are to be found, the occurrence of such a lithological type strongly implies marine influence. Although forming only thin beds, marine shales can generally be traced over wide areas without appreciable change in lithology ; they are thus of great importance as datum planes. Usually the black shales yield a fauna of goniatites (Fig. 18), nautiloids, gastropods, lamellibranchs, brachiopods, and other marine forms. Brackish-water conditions are indicated by a general absence of most of these marine forms, but the chitinous or chitino-phosphatic brachiopods *Lingula* and *Orbiculoidea* and fish-remains may occur.

The principal marine beds occur at four different levels in the sequence. The lowest, between the Farewell Rock and the Bryn or Cnapiog Seam, have long been known ; recently they have been called the Wernffrwd Marine Beds

by S. H. Jones. Near Wernffrwd, in Gower, they contain *Gastrioceras listeri, G. circumnodosum, Orthoceras sp.*, and *Dunbarella sp.* Equivalent horizons on the North Crop have yielded abundant productid brachiopods and the fish *Deltodus*. About 30 ft. above the Farewell Rock at Haroldston West, Pembrokeshire, a marine bed has yielded *Gastrioceras spp., Productus sp., Orthotetes cantrilli*, and *Dunbarella papyracea*. The fauna of these beds is comparable with that of the Halifax Hard Bed of Yorkshire and the Bullion Mine of Lancashire.

The Amman Marine Beds, also named by S. H. Jones, occur between the Lower Vein and the Nine Feet. In the Ammanford district, where they are not well displayed, the only important fossils found are lamellibranchs (*Dunbarella sp., Myalina compressa, Nuculana sp., Schizodus sp.*) ; but farther east, between Merthyr Tydfil and Ebbw Vale, measures at about the same position in the sequence contain productids and *Spirifer pennystonensis*. On the South Crop, the beds have been recognized by Evans and Simpson in the Maesteg district and by Moore in the Caerphilly basin. In Pembrokeshire a marine band at Picton Point, lying a short distance below the Timber Vein, has yielded *Productus sp., Chonetes laguessianus, Crurithyris carbonaria*, and *Aviculopecten sp.*

Occasional marine bands are encountered in the measures between the Nine Feet and Stwrin coals ; Bevan, Salter, and Howell, for example, have recorded productids and *Spirifer sp.* from above the Rhaslas Seam. The Cefn Coed Marine Beds, which form the next important horizon, occur a short distance above the Stwrin. They have been described by Ware, and have yielded crinoid remains, *Gastrioceras* aff. *globulosum, Homoceratoides jacksoni* (Fig. 18), *Anthracoceras aegiranum, Metacoceras spp.*, brachiopods, lamellibranchs, trilobites, and the unique coral *Zaphrentis postuma* ; the associated fish are *Edestus pringlei* and species of *Coelacanthus* and *Platysomus*. Recognized at several localities on the North Crop, they have also been recorded from the Maesteg district by Evans and Simpson, by Moore near Caerphilly, and by S. H. Jones in Gower, where goniatites and lamellibranchs occur. The fossils from the Cefn Coed Marine Beds are closely similar to those of the Mansfield Marine Bed of Nottinghamshire and Yorkshire, the Gin Mine of Staffordshire, the Dukinfield of Lancashire, the Bolton Marine Bed of Cumberland, and Skipsey's Marine Band of the Scottish coalfields.

The highest marine horizons, described in detail by Dix and Trueman as the Cwmgorse Marine Beds, occur between the Red Vein and the Lower Pinchin. At Cwmgorse (the type locality) and Cefn Coed, they contain a rich fauna including crinoid columnals, *Homoceratoides kitchini, Anthracoceras cambriense, Metacoceras postcostatum, Cyclonautilus dubius, Dunbarella* aff. *papyracea, Nuculana sp., Platyconcha sp.*, productids, and fish-remains. The horizon, also recognized in the Aberdare and Merthyr Tydfil districts and on the South Crop near Maesteg and Caerphilly, is probably the equivalent of the Shafton Marine Bed of Yorkshire.

The strata between the Stwrin and Lower Pinchin coals contain the richest and most abundant marine beds of the South Wales Coal Measures ; during their formation the area was on the whole at a lower level and more liable to invasion by the sea than at any other time in the Coal Measures period. No marine beds are known to occur above the Lower Pinchin Seam, and, as Trueman has emphasized, their abrupt cessation coincides with the lithological break between the shale division of the Lower Coal Series below and the highly arenaceous Llynfi Rock and Pennant Series above : the latter were obviously

deposited under much more 'continental' conditions; the later absence of marine beds also coincides with the palaeontological break between the Similis-Pulchra Zone and the Phillipsii Zone, and with the base of the Staffordian.

Coals of South Wales.—Although forming an insignificant proportion (less than 2 per cent) of the total thickness of the Coal Measures, the coal seams are the most important beds from an economic standpoint, though at one time they were in this respect subordinate to the ironstones. The coals vary considerably in nature and in their potential uses: they fall into three main types—bituminous coals, steam coals, and anthracites. Though typical samples of each of these kinds are readily distinguished, they grade into one another imperceptibly, and precise definition is sometimes a highly technical matter of chemical analysis; in this field Seyler, Pollard, Radley, and Strahan have done important work. The bituminous coals are comparatively soft and friable; they yield a high proportion (20 to 40 per cent) of volatile matter and are good house, gas, and coking coals. The carbon-content ranges from 84 to 91 per cent. Anthracite, on the other hand, is a hard stone coal of metallic lustre yielding a low proportion (3 to 8 per cent) of volatile matter and having a low hydrogen-content; it burns at high temperatures without yellow flame or smoke, and is unsuitable for the manufacture of coke. The content of carbon is high (more than 93 per cent), while that of ash is often low. Steam coals are intermediate in composition and properties between the bituminous and anthracitic types; they grade on the one hand into semi-bituminous and on the other into semi-anthracitic coals.

The distribution, both in the vertical and horizontal directions, of the different kinds of coal in South Wales shows features of unusual interest. In the first place, they obey Hilt's 'Law', the lower seams at any one locality tending to be more anthracitic than the higher. No anthracites occur in the beds above the Lower Coal Series, most of the seams in the Pennant Series being bituminous. Secondly, any one coal seam tends to become progressively more anthracitic as it is followed towards the north or north-west: thus the bituminous coals are found along the southern and eastern outcrops, the steam coals in the central part of the Coalfield between the valleys of the Taff and the Neath (particularly in the Rhondda valleys), and the anthracites in the Lower Coal Series of the North Crop westwards from the River Neath, especially along the Gwendraeth Valley; in Pembrokeshire also the coals are anthracitic.

The reasons for the regional changes are not certainly known. Some authorities suppose that all the coals were originally bituminous and that anthracitization arose subsequently owing to pressure and heat (due either to depth of burial or to earth-movements). But there is no correlation between thickness of superincumbent strata, or between intensity of earth-movement, and the degree of anthracitization. Again, the transformation of the soft plant-debris into coal occurred within a short time after burial, for eroded coal pebbles occur in the Pennant Sandstone and some, which are anthracitic, evidently came from the Lower Coal Series. Other writers consider that the present differences between the coals result from original differences in the composition of the coal-forming material; these might be due to local circumstances of accumulation, or to variations in the nature of the decaying plants, though it is fairly certain that similar plants formed both the anthracites and the bituminous coals.

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AFTER THE ARMORICAN uplift enormous denudation of the land took place before the region was again submerged. It is computed that a thickness of over 7,000 ft. of strata was removed from the district that is now the Vale of Glamorgan, and over 12,000 ft. from Gower. This great break in the stratigraphical record is emphasized by the character of the flora and fauna of the Mesozoic era, for in the interval the Palaeozoic species died out, and their places were taken by other forms of plants and animals (Fig. 25). Of the latter the most important are the ammonites and reptiles, and the Mesozoic is often referred to as the Age of Reptiles and the Age of Ammonites.

The Mesozoic strata are confined to the districts adjacent to the southern margin of the Coalfield, and are well developed in the Vale of Glamorgan.

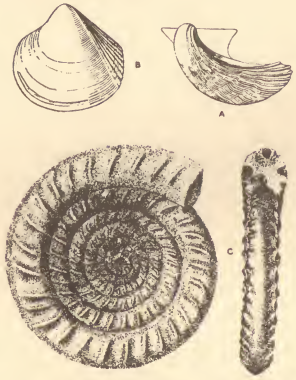

FIG. 25.—*Mesozoic Fossils* (natural size).

A, *Pteria* [*Avicula*] *contorta* (Portlock), Rhaetic Series; B, *Protocardia rhaetica* (Merian), Rhaetic Series; C, *Caloceras* cf. *johnstoni* (J. de C. Sowerby), two views, Lower Lias.

They comprise rocks belonging to two systems, the Trias and the Jurassic. The first-named is represented by the Keuper Series, whilst the Jurassic includes the Rhaetic and a portion of the Lias.

In some respects the rocks are unique in southern Britain; within the area they present two phases of development—a normal facies and a littoral facies—and their closest parallels in this country are to be found on the flanks of the Mendip Hills and in the west of Scotland. In South Wales the earlier sediments were laid down on an irregular subsiding floor of a great salt-lake basin; with continued subsidence, the lake was ultimately invaded by the sea, and the overlap and overstep of the beds provide a clear picture of the progressive

submergence of the land. As each of the formations approaches the old shore-line the normal facies is replaced by one of littoral type, so that the margins of the basin and the sites of ridges which rose as islands may be clearly recognized (Fig. 26).

Although nearly all traces of the Mesozoic rocks have been removed from districts farther west there is evidence that the lake extended through Gower into South Pembrokeshire. In the latter district the platform on which the deposits were laid down, though broadly recognizable, has been modified by later planation, especially in Pliocene times. It is highly probable that the Triassic and Jurassic sediments were not spread over all the Upper Carboniferous rocks of the Coalfield, though in places they reach the foot of the Pennant escarpment.

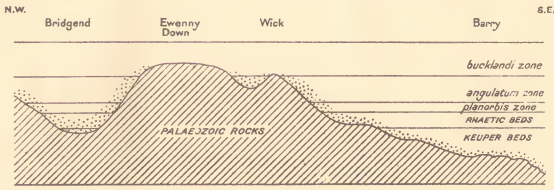

FIG. 26.—*Diagram showing the Relation of the Mesozoic Rocks to the Palaeozoic Floor.*
(After A. E. Trueman.)

As a result of continued depression, however, it is likely that the whole of the region was submerged before the close of the Mesozoic era, and it was perhaps on a sloping platform of Chalk that the rivers of South Wales were initiated.

TRIASSIC SYSTEM

Keuper Series.—In normal facies the equivalents of the Keuper Marl are about 500 ft. thick; in the Cardiff district the full development is as follows: Basal Beds up to 60 ft., Red Marls, 400 ft., Tea Green Marls, 25 to 30 ft., and probably a portion of the Sully Beds of Richardson's classification (p. 84). As already mentioned, the deposits were laid down in a lake, and the occurrence of rain-pittings, sun-cracks and reptilian footprints is evidence of frequent exposure of great mud flats during accumulation. The rocks, however, are poorly fossiliferous, suggesting that the waters were too saline to support life. In all probability the Keuper lake was surrounded by a treeless desert, since there is a general absence of plants and insect-remains as fossils.

The Basal Beds comprise breccias, conglomerates, and limestones interbedded with sandy or calcareous marl, but the constituents vary according to the character of the Palaeozoic floor on which they rest. The overlying Red Marls were deposited some distance from the shore and mainly consist of red marls with occasional green spots; in the higher beds some thin layers of gypsum occur near Penarth. As the marls approach a shore-line they pass into littoral deposits not unlike those of the Basal Beds.

A slight deepening of the basin is indicated by the Tea Green Marls, and

since they present a uniform aspect over a considerable part of the area it would seem that many of the islands in the Keuper lake had become completely submerged ; nevertheless the Marls, too, pass into a littoral facies, as is shown by the conglomerates at Coychurch and in a boring at Rhoose.

In Gower the occurrence of a few small outliers of Keuper conglomerate testify to the extension of the Keuper lake into that district. In Mewslade Bay, however, evidence of a different kind is found in the cliffs. This consists of gash-breccias ; in Pembrokeshire, where these are more prominently displayed, some of the breccias form masses that occupy as much as 200 yards of the cliff face. They consist almost entirely of limestone and dolomite-debris embedded in a matrix of calcite, red stalagmite, and red clay, and include blocks weighing up to hundreds of tons ; in every example the breccia-constituents are of material similar to that of the surrounding undisturbed rock. It is believed that the breccias originated from the collapse of the walls and roofs of huge caves which had been eroded by the solvent action of underground water in the Armorican hills from the period of their elevation until Trias times ; the red clay and stalagmite were perhaps introduced by the same agent some time later.

Another feature which may be attributed to the percolation of Triassic water is the local replacement of the top of the Carboniferous Limestone by haematitic iron-ores. The change takes place along fissures, joints, and faults, and the ore-bodies, which are of irregular shape, have been worked at Llanharry and in Garth Wood near Taff's Well.

JURASSIC SYSTEM

Rhaetic Series.[1]—The incursion of the sea into the Keuper lake was first marked by the incoming of fish, followed by molluscs ; their arrival heralded the establishment of marine conditions over the greater part of the area. The earliest deposits comprise green, grey, and blackish marls with occasional bands of marlstone, in all attaining a thickness of 14 ft. at Lavernock, where they are well displayed. The beds have been classified with the Tea Green Marls by the Geological Survey, but L. Richardson has regarded them as forming the base of the Rhaetic Series, and has given them the name of Sully Beds.

While the occurrence of *Pteria* [*Avicula*] *contorta* in association with *Ostrea bristovi* in the highest beds at St. Mary's Well Bay definitely links the deposits with those of the Rhaetic, it is a moot point whether the lower portion of the Sully Beds should not be retained in the Keuper Series. The line of division as adopted by Richardson is admittedly an arbitrary one, but if it were determined by the first occurrence of fish the junction would fall about 6 ft. from the top, where the Rhaetic fishes *Hybodus minor* and *Gyrolepis alberti* appear, and are found along with the reptiles *Mastodonsaurus*, *Palaeosaurus*, and *Trematosaurus*. In this way the Sully Beds would include only the uppermost portion of the marls ; and in this connection it may not be without significance that this base, if selected, would coincide with a layer of conglomerate seen in the cliffs at St. Mary's Well Bay.

The Rhaetic Beds of earlier writers fall into two subdivisions : a black shale group, or *Avicula contorta* Shales, 20 ft. thick, and White Lias, 11 ft. thick. From

[1] Though commonly placed by German and British authors in the Trias, the Rhaetic is here classed as basal Jurassic.

their development around Penarth and Lavernock they were known at one time as the Penarth Beds.

The *Avicula contorta* Shales are separated from the underlying beds by a sharp plane of erosion, and the submergence which brought about their deposition must have been of a sudden character as the sea spread simultaneously over a wide area. At the base there is an inconstant gritty conglomeratic layer seldom more than an inch in thickness, except where it occurs in pockets. The grit contains numerous fish scales, teeth, and reptilian coprolites, and on this account has been termed a bone-bed. Several other bone-beds occur in the overlying black shales, and yield similar species of fish, *Gyrolepis alberti* and *Hybodus minor* being abundant. The fauna of the black shales, however, is chiefly composed of lamellibranchs, such as *Chlamys valoniensis*, *Pteria* [*Avicula*] *contorta*, and *Protocardia rhaetica* (Fig. 25).

The muddy phase was followed by the more calcareous beds of the White Lias. These are whitish marls with bands of limestone and some grit. A few of the limestones are shelly and others are smooth and compact calcite-mudstones ; at the base there is a bed closely resembling the Cotham Stone of Somerset. The fauna, also largely made up of lamellibranchs, includes species of *Chlamys*, *Lima*, *Modiola*, and *Ostrea*.

Like the Keuper Series, the Rhaetic when traced westwards towards Cowbridge and Bridgend exhibits striking lithological changes. In places the shales pass into oolitic limestones, while near Bridgend they are replaced by sandstones (Quarella Stone) resembling Millstone Grit. At Pyle the arenaceous beds yield *Natica pylensis*.

Lias Series.—This formation is not completely represented in South Wales, where only a part of the lower subdivision is preserved, but in no other area in Britain are the equivalent beds of the Lower Lias better displayed than in the cliffs between Dunraven and Aberthaw.

In normal facies the Lias appears to follow the White Lias in conformable succession. At the base is a thin group of dark shales and limestones, crowded with *Ostrea liassica*. The beds are succeeded by about 30 ft. of similar but more typically marine sediments in which ammonites make their appearance ; then follows a prominent development of shales (Lavernock Shales) 100 ft. in thickness, which in turn are capped by about 200 ft. of nodular limestones.

The rocks of the lower part of the succession when traced westwards are found to pass into beds of littoral character, and in this marginal facies two chief rock-types occur, the Sutton Stone and the Southerndown Beds, but these types occasionally merge. The Sutton Stone is a massive whitish conglomeratic limestone, often showing curious pressure-sutures ; it contains large boulders of Carboniferous Limestone. Some of the beds are shaly, but at certain localities, particularly in the neighbourhood of ' islands ' of Carboniferous Limestone, corals, such as *Montlivaltia*, *Isastraea*, and *Thecosmilia*, are abundant. The Southerndown Beds, on the other hand, contain few corals ; the rocks are generally darker in colour and breccias of cherts and limestone-debris are present. In the Cowbridge district the littoral deposits are more varied and include oolitic limestones, sandy limestones, and limestone conglomerates.

The nodular limestones of the upper part of the Lias occupy a wider outcrop without undergoing any marked lateral changes of lithological characters, and it seems likely that the subsidence had advanced far enough to bring about

the submergence of all the islands which were prominent in earlier Liassic times. It is probable that at this stage the sea extended into Gower, although no actual deposits have been found *in situ*.

The fossils have attracted a considerable amount of attention, as the fauna includes many species of corals, crinoids, lamellibranchs, cephalopods, fishes, and saurians. A zonal classification based on the ammonites shows that the Pre-Planorbis, Planorbis, Angulatum, Bucklandi, and Semicostatum Zones are well represented. The most recent account of the beds is that given by A. E. Trueman, and his critical studies of the ammonites and of the lamellibranch *Gryphaea* have enabled him to establish a number of subzones.

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NO ROCKS OF MESOZOIC AGE younger than the Lias occur in South Wales, though it is not unlikely that at least some were deposited and subsequently eroded. In particular, it has been suggested by Ramsey, Jukes-Browne, Strahan, and others that the Chalk, laid down in fairly deep water and transgressive over most older rocks, at one time extended over much of South and Central Wales, only perhaps the highest mountains, such as the Brecon Beacons, projecting above its surface as islands in the Cretaceous sea. To this late-Mesozoic marine transgression has been attributed the regularity of profile of the high plateau of both the Lower Palaeozoic country and the Coalfield, the plateau feature itself being then interpreted as the relic of the Cretaceous sea-floor, from which all deposits have been eroded.

Drainage System.—In Tertiary times renewed elevation of the remnants of St. George's Land caused a retreat of the sea towards the south-east, and the Cretaceous deposits were radially tilted about the central dome situated somewhere near Snowdonia. On this newly exposed surface the river system of South Wales was perhaps initiated, the streams flowing seawards down the dip-slope towards the south and south-east. In the course of time the soft Mesozoic strata were rapidly removed by denudation, and the rivers, cutting through them but still retaining their southerly trend, reached the foundation of Palaeozoic rocks beneath; that is, the rivers, normally developed on a gentle dip-slope, became superimposed on complex geological structures to which they bear no relationship.

The superimposed subradial drainage system has, however, in many cases been modified by river capture. Thus it is highly probable that some of the tributaries of the Towy, including parts of the Cothi, once continued southwards across the site of the present Vale of Towy to flow into the Gwendraeth or Loughor valleys. The Upper Towy itself probably continued south-eastwards to join the Usk at Trecastle, and the Upper Irfon south-eastwards to join the Usk near Sennibridge. Similarly the gap between Llandyssul and Carmarthen may have been occupied by an early River Teifi. Such capture has been effected by comparatively rapid errosion along belts of structural weakness, the Caledonoid Towy, Cothi, and Teifi anticlines being dominating elements controlling differential erosion. Similar river capture along the lines of the Caledonoid disturbances in the development of the Neath and Tawe drainage systems has been shown by R. O. Jones to have taken place in relatively recent times long after all traces of any Mesozoic cover had been removed.

Tertiary Deposits.—Whether or not the broad outline of the upland physiography and the drainage system be thus explained satisfactorily in terms of an extensive covering of Chalk during early Tertiary times, it is fairly certain that most of South Wales was dry land throughout that era. The evidence of the Eocene and Oligocene deposits of southern England is conclusive that during those periods the sea retreated to the south and east of Wales. The succeeding Miocene was the period when the last of the intense orogenic movements affected Britain. The only rock that may possibly be ascribed to one of these periods exists as a small pocket of pipe-clay found in the limestone plateau at

Flimston in South Pembrokeshire. The deposit, at least 45 ft. thick, consists of a mottled and striped greasy plastic unfossiliferous clay associated with quartz-marl and quartz-gravel probably of later date. It has been compared by Dixon with some of the Tertiary deposits of southern England, particularly with the Bovey Tracey Beds of Devon, which also consist in part of plastic pottery clays. He has suggested that, like the Bovey Tracey Beds, it accumulated during Oligocene times as the fine sediment of a local freshwater lake.

Earth-movements.—Reference has already been made to the occurrence of broad folding, with some faulting, in the Mesozoic rocks of the Vale of Glamorgan, which O. T. Jones has considered to be ripples of the Miocene Alpine orogeny. Although these folds have an inappreciable effect on the much more intense Armorican folds of the underlying Upper Palaeozoic rocks, they are sufficient to throw the Triassic and Liassic strata into earth-waves of amplitudes reaching several hundred feet—sufficient, that is, to have had an obvious effect on any plane erosional platforms that may have existed at the time of the orogeny. But the coastal plateau (see below) of the Vale of Glamorgan, of Gower, and of Carmarthenshire and Pembrokeshire displays several erosion planes which are almost horizontal ; it is therefore practically certain that their final planation took place in post-Miocene times, even though considerable erosion during the Mesozoic left its impress, as is indicated by the Triassic outliers in Gower and South Pembrokeshire.

The coastal plateau is a vaguely defined area, usefully distinguished from the high plateau, as a composite land surface made up of several different platforms. The most obvious of these is sharply cut both in Gower and South Pembrokeshire (Pl. V) across the upturned edges of more or less steeply dipping Upper Palaeozoic rocks, without regard to geological structure or to the etching out of hard and soft beds. Except in South Pembrokeshire, where thin quartz-gravels may be contemporaneous beach deposits, no sediments associated with this platform are known, but its perfect form enforces the conclusion that it is the product of marine erosion. In Gower it is strongly developed at a height of about 200 ft. above present sea-level, though it ranges both above and below this altitude ; in South Pembrokeshire it drops to appreciably lower levels. It may also be recognized, though less clearly, cut in the folded Mesozoic sediments of the Vale of Glamorgan.

A higher platform, at a height of about 400 ft. above sea-level, is seen in the Vale of Glamorgan, in Pembrokeshire, and along the shores of Cardigan Bay, though it is considerably dissected and does not display the perfection of planation of the lower platform ; it is not easily recognized in Gower owing to the encroachment of the lower platform.

Yet another platform, at about 600 ft. above sea-level, is well marked in northern Pembrokeshire and in Cardiganshire, the monadnocks of Carn Llidi and Pen Bery near St. David's (Pl. IVb) probably being outlying relics. In Gower also the isolated hills of Old Red Sandstone reach approximately the same height and serve to confirm the continuity of the feature eastwards.

All these platforms, being later than the folding of the Mesozoic rocks, indicate emergence probably Pliocene in age. Similar platforms at about the same heights, unaffected by (and therefore later than) the Miocene movements that folded the Eocene and Oligocene strata, may be recognized in southern England ; they also seem to occur in North Wales.

The emergence caused a progressive lowering of the base-level to which the

rivers of South Wales were graded, and many of them, mature in their upper reaches, show rejuvenation and readjustment towards their mouths. Thus O. T. Jones has demonstrated that uplifts of about 580 ft. and 400 ft. respectively have modified the thalweg of the River Towy, while many of the tributaries of the Neath also appear to ' hang ' above the main stream by some 400 ft. In the Aberystwyth district the upper reaches of the Rheidol and Teifi rivers likewise bear clear evidence of uplift of about 400 ft. As Jones and Pugh have shown, this rejuvenation has resulted in a modification of drainage, the mature headwaters of the original Teifi having been captured by westward-flowing young streams rapidly eroding backwards along steep-sided gorges. These streams, the present Rheidol and Ystwyth, cross the Caledonoid structure more or less at right angles, though erosion by the Ystwyth has been facilitated by the belt of crushing and weakness along the line of the powerful Ystwyth Fault. Some of the tributaries of the Towy, Loughor, Tawe and Avon have an irregular long-profile, suggesting they were graded to the 200-ft. platform, and hang above the main stream to that degree. Where the high plateau is contiguous with the Vale of Glamorgan the deep trench-like valleys of the eastern and central parts of the Coalfield suddenly come to an end when their rivers emerge on to the low gentle slopes of the coastal plateau.

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X. THE PLEISTOCENE AND RECENT DEPOSITS

Glaciation.—The only extensive deposits in South Wales younger than the Lias are the tracts of unconsolidated Glacial drift that mask the ' solid ' rocks over much of the upland and the greater part of the lowland areas. These superficial beds are the product of the glaciation that occurred during the Great Ice Age of Pleistocene times, and demonstrate that during that period the whole of South Wales was covered by an extensive and more or less continuous sheet of ice.

As the climate of early Quaternary times became progressively more arctic, snow and ice accumulated on the summits of the higher hill ranges ; the ice-caps, increasing in size, ultimately flowed downhill as glaciers, the separate flows sooner or later coalescing to form unbroken sheets of ice. The movement of the ice under the force of gravity conformed broadly with the topography which had been carved out by prolonged erosion during Tertiary times and which in its essential features was similar to that of to-day (Fig. 27).

The chief glacial outlets were along the major valley courses. From the Plynlimon range much ice moved off directly into the sea of Cardigan Bay ; much flowed into the valley of the Teifi to form the Teifi Glacier with its ultimate outlet in Cardigan Bay ; but there was also a considerable landward flow, on the one hand into the Severn Valley on the north-east, on the other into the low ground about Rhayader, Builth, and Llanwrtyd Wells, from which the ice escaped largely along the Wye Valley into the Herefordshire Plain. From the hills around Drygarn, north and north-west of Llandovery, an ice-cap, probably continuous with the larger one on Plynlimon, nourished valley glaciers which merged with ice from the east to form the Towy Glacier that debouched into Carmarthen Bay.

Mynydd Eppynt carried a small independent ice-sheet that moved eastwards and south-eastwards into the Wye and Usk glaciers. At times, however, the passage through the upper part of the Irfon Valley was sufficiently clear to allow some of the ice to overflow the divide into the Towy. At other times Drygarn–Plynlimon ice was powerful enough to override the scarp front of Mynydd Eppynt and flow into the Usk Valley.

Farther south the principal collecting ground was the hill country of the Old Red Sandstone forming the Carmarthenshire Fans and the Brecon Beacons. The steep northern face of this range was the source of numerous corrie glaciers, most of which flowed into the Usk and merged with the ice from Mynydd Eppynt and from the Black Mountains. Much of the ice from the Carmarthenshire Fans flowed north-westwards to join the Towy Glacier. The long dip-slopes towards the south, however, were the feeding-ground of far greater quantities of ice, which as powerful glaciers and sheets was able to cross much of the upland of the Coalfield. The only barrier that effectively shouldered off this Fans–Beacons ice, and which nourished a small ice-cap of its own, was the escarpment of Pennant Sandstone of Craig-y-Llyn (Pl. IIB), which itself poured ice into the Neath and Cynon and on its south side into the Avon, Llynfi, Ogmore, and Rhondda valleys. The major outlets for this southward-flowing composite ice-drift were the Loughor, Tawe, and Neath valleys in the

west, and the Taff, Rhymney, and Ebbw valleys on the east; the 'local' ice of the Gwendraeth and Loughor valleys in the west of the Coalfield was also joined by overflows from the Towy Glacier, particularly through the low col near Llandebie into the Loughor Valley, where erratics of Llangadock rhyolite are common. The coastal lowlands of Carmarthenshire, Gower, and the Vale of Glamorgan were then covered by a piedmont ice-sheet formed by the coalescence of these separate flows; it extended for an unknown distance into the Bristol Channel.

All the ice-flows so far described are strictly 'local' in character, in the sense

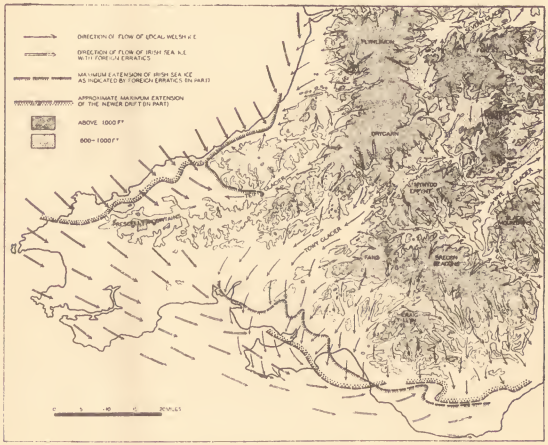

FIG. 27.—*Map illustrating the Glaciation of South Wales.*

The arrows are generalized and no discrimination is made between the slightly different directions of ice-flow of Older Drift and Newer Drift times. At its maximum extension the Irish Sea Ice probably covered or nearly covered the Prescelly Mountains and its boundary may have run north-eastwards from the mouth of the River Towy through the Carmarthen-Llandyssul gap to the Teifi Valley.

(In part after Charlesworth, Williams, Dwerryhouse and Miller, and Griffiths.)

that they originated in the hills of South Wales and moved seawards or on to neighbouring lowland down the most easily accessible routes available. Only occasionally and in minor degree, as when Plynlimon ice spilled over the col between the Irfon and Towy valleys, was there interference of one glacial drainage system with another.

But while this local glaciation came into being, great ice-flows from diverse sources were commingling and piling up in the depression of the Irish Sea and St. George's Channel to form one of the largest and thickest glaciers affecting the British Isles during the Pleistocene period. This mer-de-glace debouched southwards, and impinged upon the coast of Cardigan Bay and North Pem-

brokeshire. Under great pressure it was sufficiently powerful to rise to heights of many hundred feet along the coastal plateau of Cardiganshire, despite the outward thrust of Plynlimon ice. Farther south, where the influence of local ice was not so great, it was able to ascend the Teifi Valley for a score of miles and to overflow the col between Llandyssul and Carmarthen to join the Towy Glacier. In North Pembrokeshire the Irish Sea ice overrode, at least in great part, the Prescelly Mountains, and, expanding along the depression of the Bristol Channel, crossed Carmarthen Bay to Gower, and thence eastwards to the Vale of Glamorgan.

The extension of this far-travelled ice is attested by the occurrence of boulders in the Glacial drifts that are of rock-types not found *in situ* in South Wales. These erratics, although often found in boulder clay and gravel mixed with much local material, can be matched by rock-in-place that outcrops in distant parts of the Irish Sea shores. Thus a common type of drift pebble found both in Pembrokeshire and Gower has its counterpart in the granites and other igneous intrusions of the Southern Uplands of Scotland (the Dalbeattie and Castle Douglas intrusive suite). Erratics of the Goat Fell granite of the Isle of Arran have been found on the Cardiganshire coast and in Gower, while both these areas have also yielded pebbles of the characteristic Ailsa Craig riebeckite microgranite. Rocks from the English Lake District have not been certainly recognized in South Wales, but rhyolites and rhyolitic ashes and tuffs from North Wales are common. On the Carmarthenshire lowlands and in Gower erratics from Pembrokeshire are relatively abundant, characteristic pebbles from the quartz-feldspar porphyry of Ramsey Island possibly being the most frequent individual rock-type. The coastal drifts of Cardigan Bay and Gower have also yielded fragments of Mesozoic rocks and fossils (of Liassic and Middle Jurassic age) that could only have come from outcrops either in Northern Ireland or (more probably) in the Western Isles of Scotland. Flints of Cretaceous (Chalk) age, probably from the same sources or from drowned outcrops in the floor of the Irish Sea, are also scattered widely through the lowland drifts of South Wales, and are particularly common in the Vale of Glamorgan, where far-travelled igneous erratics are comparatively rare. The most easterly occurrences of Irish Sea drift at present known are around Cardiff, where felsite pebbles from North Wales have been collected. Scottish, North Wales, and Pembrokeshire rocks have also been found in the Bridgend and Cowbridge districts. Associated with the igneous erratics in the gravels of the Cardiganshire and North Pembrokeshire coast are pockets of sand with marine shells of arctic type, such as *Tellina* (*Macoma*) *baltica*, *Cyprina islandica*, and *Astarte borealis*, that were carried inland after being dredged from the sea-floor by the south-eastward-moving ice.

The complication arising from the occurrence of two major types of ice-stream in South Wales (the local Welsh ice and the ice from the Irish Sea) is enhanced by the glaciation itself being multiple and composite in time. That is, there was not a single simple descent of the ice from the hills followed by an amelioration of climate with glacial retreat, but a succession or repetition of glacial phases separated by a relatively genial interglacial phase. The most complete evidence for the composite nature of the glaciation occurs along the shores of Cardigan Bay and North Pembrokeshire, where Jehu and Williams have shown that a lower and an upper boulder clay, both of glacial origin, are separated by an interbedded series of fluviatile sands and gravels deposited

when the land was relatively ice-free. In South Wales, Charlesworth has traced the relics of the second glaciation (the Newer Drift) and has demonstrated that they do not cover such an extensive area as those of the first (the Older Drift) ; their margin can be more or less easily recognized by the mounds of sand and gravel that constitute the terminal moraine of the Newer Drift. Moreover, during the second glaciation ice from the Irish Sea, also not so extensive as that of the first, impinged upon the shores of Cardigan Bay and North Pembrokeshire, but did not cross into Carmarthenshire and Glamorgan, where the Newer Drift consists only of locally derived material. Inland, where the parent sources and the directions of flow of the Newer Drift ice were the same as those of the Older, it is often difficult to distinguish between the deposits and the effects of the two glaciations ; it is clear, however, that the second was much less powerful than the first, Newer Drift of Fans–Beacons origin being mainly confined to the larger valleys, and overriding only the flanks of the higher hills of the Coalfield. Minor halt stages in the final retreat of this ice are marked by small transverse moraines in many valleys.

Apart from the extensive spreads of boulder clay and gravel that mark the former extent of the ice, the effects of glaciation are strongly delineated in the modification of the pre-Glacial topography. The development of corries and cirques on the scarp faces of the Pennant Sandstone and the Old Red Sandstone has already been noticed ; they also occur at the heads of many of the streams leading from other centres of ice accumulation, particularly around Plynlimon. Some of them, such as Llyn-y-Fan at the head of the River Tawe and Llyn Fawr beneath the brow of the Pennant ridge of Craig-y-Llyn, contain small moraine-dammed lakes ; these lakes are not uncommon in the Plynlimon range, the source of the Rheidol being in one at the foot of Plynlimon itself. Many of the valleys have been intensely carved by the ice : for example, those of the Neath and Tawe are typically U-shaped, as are the valleys of the Dyfi, Rheidol, and Ystwyth. Gouging by the ice has also caused some over-deepening, though few true rock basins are known.

During the later stages of glaciation along the coast of Cardigan Bay, when the local Welsh ice had withdrawn some distance inland, Irish Sea ice still existed as a slowly retreating barrier across the river mouths ; consequently the free drainage of the area was impeded, and the impounded waters collected as temporary lakes which discharged southwards through high-level overflow channels into neighbouring valleys. These have been shown by Jones and Pugh to be well displayed in the Aberystwyth district, but the largest occurred in the Teifi Valley (' Lake Teifi ') (Fig. 28) ; this drained southwards into a lake at a lower level in the Nevern Valley, which in turn overflowed at times through the present Gwaun Valley into Fishguard Bay. It is probable that at the time of maximum extension of the Irish Sea ice during the period of the Newer Drift, the ultimate drainage of this lake system to the sea was through a channel at Jordanston into the upper reaches of the Western Cleddau and so to Milford Haven. Compararable lakes, dammed by Irish Sea ice occupying the Bristol Channel, probably existed during the later stages of the Older Drift glaciation of the Loughor and Tawe valleys, where anomalous gaps appear to be overflow channels ; but the evidence has been partly masked by the later glaciation.

Raised Beaches.—Reaching heights of 20 to 30 ft. above present-day high water mark, raised beaches occur intermittently wherever the nature of the coast is suitable for their formation and preservation. In particular, they are

well displayed along the foot of the limestone cliffs forming much of the coast of Gower and South Pembrokeshire. The most prominent of these beaches is that first recognized by Tiddeman, which has been called the Patella Beach because of the abundance of limpets it contains ; associated with the limpets are numerous periwinkles and dog-whelks. This beach may occur as a deposit of shelly shingle and pebbles, generally cemented by stalagmitic material into a hard conglomerate, resting on a well-planed, though narrow, marine wave-cut platform (Pl. VIIa) ; more usually the platform may be recognized though

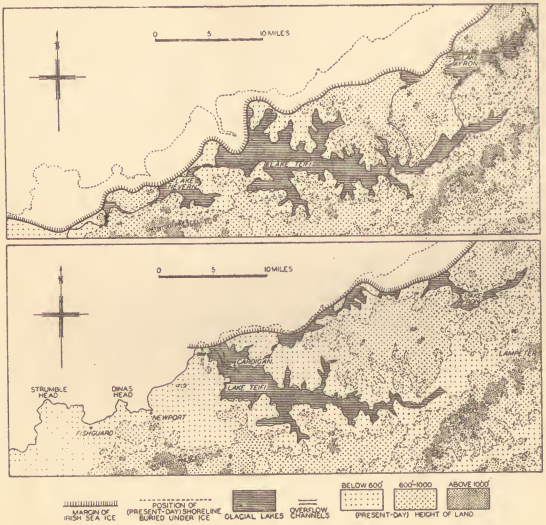

FIG. 28.—*Late-Glacial Ice-dammed Lakes in Cardiganshire and North Pembrokeshire.*

The upper map shows a stage when the Irish Sea Ice was relatively far inland, the ultimate outflow of the lake system being then south-westwards *via* the Jordanston Channel into the upper reaches of the Cleddau. The lower map shows a later stage when the Irish Sea Ice had begun to retreat, and the lakes were reduced in size and drained directly into Cardigan Bay.

(After J. K. Charlesworth.)

no contemporary deposits remain. Wherever the two occur in association, the Beach is seen to be overlain by Glacial deposits ; as these deposits in western Gower belong to the earlier glaciation, it follows that the Beach is pre-Glacial in being older than the oldest known drift (the Older Drift) of South Wales. The pebbles in the Beach are thus largely free from erratics, though igneous rocks of extra-Welsh origin have been occasionally recorded from both South Pembrokeshire and Gower ; these may have been carried by drifting ice at a time of onset of arctic conditions. Along the banks of Milford Haven a platform just

above high water mark may be the continuation of the same raised beach ; in places it supports material, underlying Glacial drift, comparable with offshore tidal mud-with-stones. Many of the bone caves of Gower and Pembrokeshire open on to the platform of the Patella Beach and it is probable that they were excavated, or at least enlarged, by marine action along faults and joints at the same time as the platform was planed. At that time the modern beach platform had not been carved, and subsequent access to the caves by prehistoric animals was easily effected over the pavement of the Patella Beach.

In Gower (Minchin Hole) there is evidence of another beach, the Neritoides Beach, also probably older than the Older Drift, but overlying (and therefore younger than) the Patella Beach from which it is separated in places by a bone-bearing terrestrial cave breccia.

A third ancient beach, the Heatherslade Beach, also occurs in Gower ; it contains an abundance of erratic pebbles derived from the neighbouring Glacial gravels, and it is certainly much younger than the Older Drift, being possibly entirely post-Glacial in age. Remnants of the beach, consisting of a concreted shelly conglomerate and shingle, are found below present-day high water mark resting directly on the modern beach platform. It would seem, therefore, that this ' modern ' wave-cut plane of denudation is not of recent origin, but, carved at the time of formation of the Heatherslade Beach, has since undergone considerable elevation and subsidence, finally to return coincidentally to its original level. Its perfect planation, thus referred to an ancient date, is much more satisfactorily explained than on the assumption that it has been formed during the brief interval that has elapsed since the accumulation of the Submerged Forest Series (p. 96).

Bone Caves.—Many of the caves of Gower, eroded in the Carboniferous Limestone and opening on to the platform of the Patella Beach, were the habitations of prehistoric animals at a time when the land was appreciably higher above sea-level than it is at the present day. These caves contain thin deposits of cave earth and breccia often rich in mammalian bones of Pleistocene age. The most important is Paviland, described in detail by Sollas, who showed that it was more or less continuously occupied by men of the Cro-Magnard race throughout most of Aurignacian, and possibly at the beginning of Solutrean, times of the Old Stone Age—that is, throughout much of the temperate interlude between the glaciations of the Older and Newer Drifts. Artefacts associated with the few human bones (which appear to have been interred) include numbers of chipped flint flakes and some ornaments of ivory and bone, all characteristic of the Upper Palaeolithic Age. The bones of other animals were also abundant and included many of horse, bear, and ox together with mammoth (*Elephas primigenius*), woolly rhinoceros (*R. tichorhinus*), Irish elk, wolf, and reindeer. The fauna as a whole is of a cold temperate type, suggesting that steppe conditions characterized this Aurignacian climatic oscillation in South Wales. Other caves in Gower contain many Aurignacian implements, but none has yielded human bones of Palaeolithic age ; the implements are usually associated with a ' cold ' fauna comparable with that of Paviland. In other caves, notably Bacon Hole and Minchin Hole (where it is associated with the Neritoides Beach), an older fauna (earlier than the Older Drift) without human relics includes the straight-tusked elephant (*Elephas antiquus*) and the slender-nosed rhinoceros (*R. hemitoechus*) that appear to have lived at a time when the climate was appreciably warmer than that of the present day. A few of the

caves, containing many hundreds of bones, were probably hyaena dens, and one, where over a thousand shed antlers were collected, was obviously a haunt of red deer.

Similar caves occur along the Pembrokeshire coast, where, however, the most important Palaeolithic site, Hoyle's Mouth near Tenby, is at a considerable height above sea-level and has been formed by solution of the Carboniferous Limestone by percolating underground waters ; it has yielded implements of Aurignacian type associated with a ' cold ' fauna of reindeer, red deer, wolf, and bear. Other inland caves, formed by solution in the Carboniferous Limestone, occur along the North Crop in Carmarthenshire and Breconshire.

Recent Deposits.—The principal post-Glacial deposits are found along the coast, where extensive tracts of blown sand, piled by the prevailing winds, occur particularly in Carmarthen and Swansea bays. These dunes seriously impede drainage, and behind them in many parts there are winding stretches of flat alluvial marshland running parallel with the coast ; this feature is well displayed between Swansea and Porthcawl, and on a smaller scale south of Kidwelly and at Oxwich ; farther north, Borth Bog at the mouth of the River Dyfi is protected from the sea by a sand spit several miles long.

During the New Stone (Neolithic) Age similar conditions appear to have been widespread around the South Wales coast, the majority of the bays displaying evidence of ancient marsh conditions, even where such no longer exist, in the presence of lacustrine, estuarine, and terrestrial sediments. These strata, known as the Submerged Forest Series, are usually exposed at or below high water mark of present-day tides in positions where they could not possibly be formed now. The terrestrial accumulations are soils that have been compacted to form peat ; stools of trees, still in position of growth, are common in them, and their mass is often made of twigs, branches, and leaves of such plants as oak, hazel, alder, and birch that must have grown on relatively dry ground at least a few feet above sea and marsh level. Seen in Cardigan Bay (the site of Cantref-y-Gwaelod) and in Pembrokeshire, they have also been particularly well exposed in dock and other excavations in the Glamorgan ports, where the various developments show a succession of peats interbedded with silts, muds, clays, and gravels. The details are illustrated in Fig. 29, from which it is clear that South Wales suffered in post-Glacial times considerable subsidence ; on the assumption that the lowest peat beds accumulated at a height of at least 20 ft. above Ordnance Datum (so that the living plants were free from inundation by the sea), this subsidence must have been of the measure of at least 75 ft., and the coast has been drowned to a corresponding degree. The subsidence, however, was not uniform and regular, but was intermittent and oscillatory in nature, with alternations of freshwater and even marine sediments intercalated with the peats ; the freshwater strata contain not only reeds and sedges, but also such typical marsh snails as *Limnaea*, *Planorbis*, *Hydrobia*, and *Ancylus* ; the brackish-water estuarine and marine beds contain the bivalves *Scrobicularia* and *Tellina* together with Foraminifera. The present-day alluvium of the coastal flats is only the latest of these deposits, and the oscillations begun in Submerged Forest times have probably not yet come to an end, although no appreciable change in the position of sea-level has occurred during historic times. Associated with the plants in the peat beds are remains of insect life (the elytra of beetles are especially common) together with bones of mammals some of which, such as the red deer, roe deer, and auroch, no

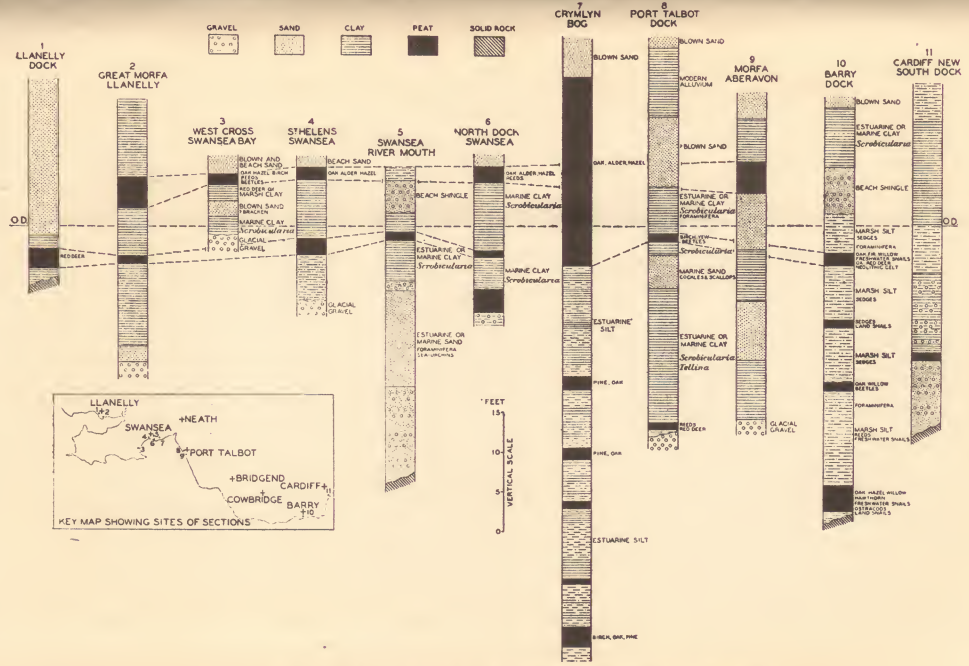

FIG. 29.—*Comparative Vertical Sections of the Submerged Forest Series of South Wales.*
The suggested correlations of peat-beds are only approximate.

longer live in Wales. Flint implements and flint-working sites associated with the highest submerged peat in Pembrokeshire and Glamorgan show that the forested land was then sufficiently dry and protected to be, at least temporarily, the habitation of man ; the artefacts are typical products of the Neolithic Age.

The drowning of most of the larger valleys around the coast of South Wales is in part to be attributed to the regional subsidence marked by the Submerged Forest Series (though some subsidence had already occurred before the close of Tertiary times). The ria of Milford Haven is the clearest example of such drowning. In other cases the effect of subsidence is obscured by the occurrence of thick accumulations of drift and alluvium that choke the valley mouths ; but boreholes, particularly in the Tawe Valley, have proved the ' solid ' rock floor to lie in places more than 150 ft. below present-day sea-level.

Inland, the only notable Recent deposits are the peat bogs often found in the wilder mountainous districts occupied by the Upper and Lower Palaeozoic rocks, and the river alluvium of most of the valleys. The upper reaches of the River Teifi near Tregaron flow through wide alluvial tracts, in part converted to peat bog ; these flats were at one time the floors of lakes dammed behind transverse moraines formed during the Newer Drift glaciation, the lakes being later drained through outlets incised in the moraines by stream-erosion.

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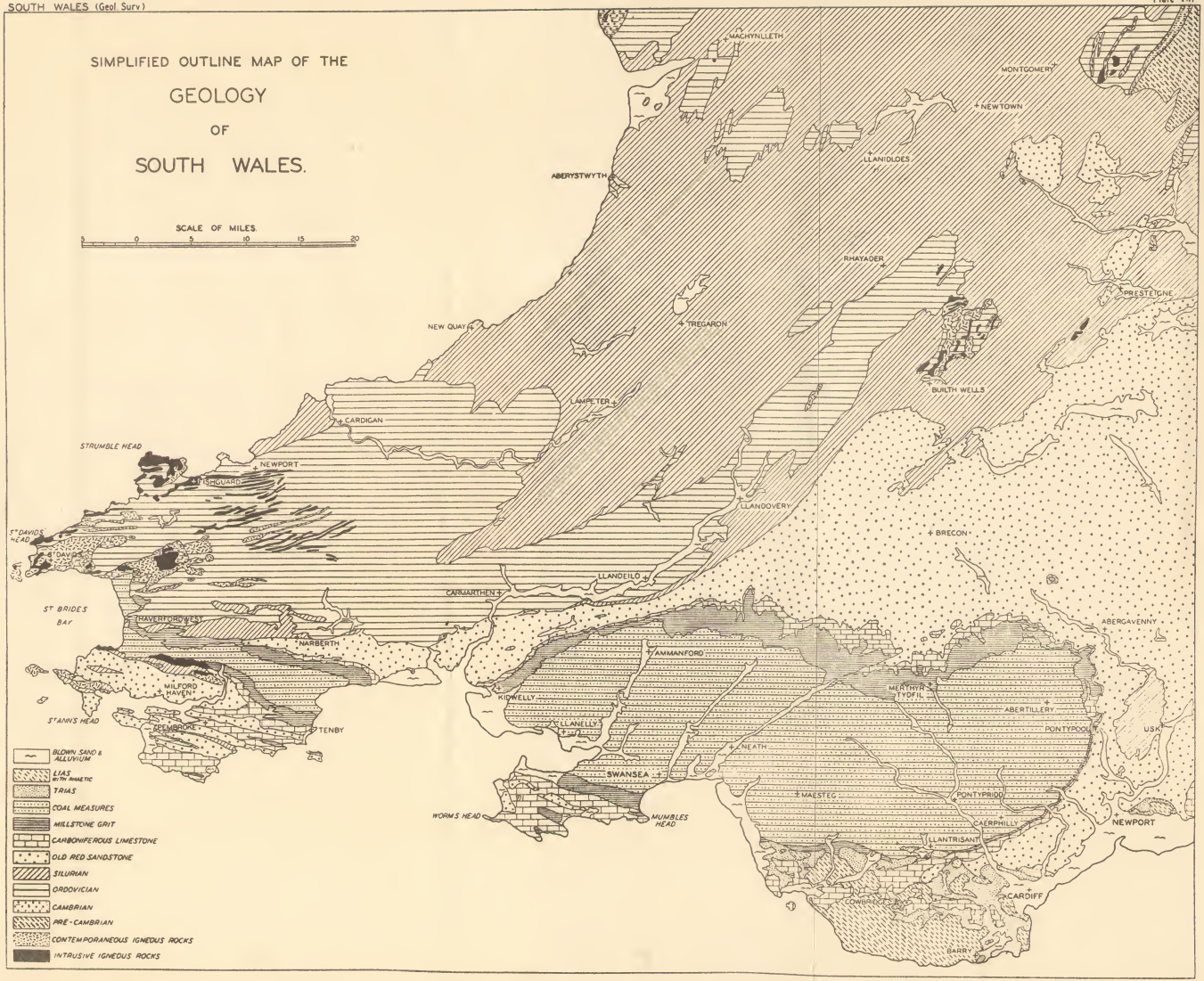
Note on Plate VIII (opposite). The evidence for the outliers of Silurian rocks west of Cardigan requires investigation.


SIMPLIFIED OUTLINE MAP OF THE
GEOLOGY
OF
SOUTH WALES.
SCALE OF MILES.
5 0 5 10 15 20
MACHYNLLETH
MONTGOMERY
NEWTOWN
LLANIDLOES
ABERYSTWYTH
RHAYADER
PRESTEIGNE
NEW QUAY
TREGARON
BUILTH WELLS
LAMPETER
CARDIGAN
STRUMBLE HEAD
NEWPORT
FISHGUARD
LLANDOVERY
ST DAVID'S HEAD
BRECON
CARMARTHEN
LLANDEILO
ST BRIDE'S BAY
HAVERFORDWEST
NARBERTH
ABERGAVENNY
AMMANFORD
MILFORD HAVEN
MERTHYR TYDFIL
RHYDWELLY
ABERTILLERY
ST ANN'S HEAD
LLANELLY
PEMBROKE
TENBY
PONTYPOOL
USK
NEATH
SWANSEA
MAESTEG
PONTYPRIDD
WORM'S HEAD
MUMBLES HEAD
CAERPHILLY
NEWPORT
LLANTRISANT
CARDIFF
COWBRIDGE
BARRY
BLOWN SAND & ALLUVIUM
LIAS WITH MARGETIC
TRIAS
COAL MEASURES
MILLSTONE GRIT
CARBONIFEROUS LIMESTONE
OLD RED SANDSTONE
SILURIAN
ORDOVICIAN
CAMBRIAN
PRE-CAMBRIAN
CONTEMPORANEOUS IGNEOUS ROCKS
INTRUSIVE IGNEOUS ROCKS

XI. APPENDIX

MAPS AND PUBLICATIONS DEALING WITH SOUTH WALES[1]

Memoirs of the Geological Survey

The Coals of South Wales, with Special Reference to the Origin and Distribution of Anthracite. 2nd Edition. 1915.

The Geology of the South Wales Coalfield. Part I. The Country around Newport, Mon. (Sheet 249). 2nd Edition. 1909.

——. Part II. Abergavenny (Sheet 232). 2nd Edition. 1927.

——. Part III. The Country around Cardiff (Sheet 263). 2nd Edition. 1912.

——. Part IV. The Country around Pontypridd and Maesteg (Sheet 248). 2nd Edition. 1917.

——. Part V. The Country around Merthyr Tydfil (Sheet 231). 2nd Edition. 1932.

——. Part VI. The Country around Bridgend (Sheets 261–2). 1904.

——. Part VII. The Country around Ammanford (Sheet 230). 1907.

——. Part VIII. The Country around Swansea (Sheet 247). 1907.

——. Part IX. West Gower and the Country around Pembrey (Sheet 246). 1907.

——. Part X. The Country around Carmarthen (Sheet 229). 1909.

——. Part XI. The Country around Haverfordwest (Sheet 228). 1914.

——. Part XII. The Country around Milford (Sheet 227). 1916.

——. Part XIII. The Country around Pembroke and Tenby (Sheets 244 and 245). 1921.

Special Reports on Mineral Resources

Vol. VI. Refractory Materials: Ganister and Silica-Rock, Sand for Open-Hearth Steel Furnaces, Dolomite. Resources and Geology. 2nd Edition. 1920.

Vol. X. The Haematites of the Forest of Dean and South Wales. 2nd Edition. 1927.

Vol. XIII. Iron Ores: Pre-Carboniferous and Carboniferous Bedded Ores of England and Wales. 1920.

Vol. XIV. Refractory Materials: Fireclays, Resources and Geology. 1920.

Vol. XVI. Refractory Materials: Ganister and Silica-Rock, Sand for Open-Hearth Steel Furnaces, Dolomite. Petrography and Chemistry. 1920.

Vol. XX. Lead and Zinc. The Mining District of North Cardiganshire and West Montgomeryshire. 1922.

Maps of the Geological Survey

QUARTER INCH TO ONE MILE—Nos. 13, 14, 18 (1929–31).

NEW SERIES ONE-INCH SHEETS (COLOUR-PRINTED). (One inch to one mile.)

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230.—Ammanford. 1907.
231.—Merthyr Tydfil. *Revised* 1922.
232.—Abergavenny. 1902; Drift Edition, *Revised* 1932.
244.—Linney Head. 1921.
245.—Pembroke. *Reprinted with National Grid.* 1946. 2s. 6d.
246.—Worms Head. 1906.
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249.—Newport, Pontypool. *Revised* 1922.
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244.—Linney Head. 1921.
245.—Pembroke. 1921.

[1] Stocks of Geological Survey publications were destroyed by enemy action.

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The Old Series Sheets relating to South Wales which are not completely replaced by New Series maps are still obtainable. They are published in a Solid Edition only and are hand-coloured.

SIX-INCH SHEETS. (Six inches to one mile.)

The Six-inch Sheets relating to the mining areas contained in the New Series One-inch Sheets are published, hand-coloured, most of them in both Solid and Drift editions.

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The following sheets of sections of Shafts in the South Wales Coalfield are published or are being reprinted :—

Sheet 80.
Sheets 81, 83, 84, 85, 87, 93.

Private and Other Publications dealing with South Wales

1920. COX, A. H. The Geology of the Cardiff District. *Proc. Geol. Assoc.*, vol. xxxi, p. 45.
1910. FEARNSIDES, W. G. North and Central Wales. *Jubilee Vol. Geol. Assoc.*, p. 786.
1939. GEORGE, T. N. *The Geology, Physical Features and Natural Resources of the Swansea District.* Cardiff.
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